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AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

(INCORPORATED)

American Institute of Mining, Metallurgical and Petroleum Engineers

PETROLEUM DEVELOPMENT AND TECHNOLOGY 1931

[v. 92]

PETROLEUM DIVISION

PAPERS AND DISCUSSIONS PRESENTED BEFORE THE DIVISION AT TULSA, OCT. 2–3, AND LOS ANGELES, OCT. 17, 1930, AND NEW YORK, FEB. 16–19, 1931.

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LETTER OF TRANSMITTAL

H. Foster Bain, Secretary,
American Institute of Mining and Metallurgical Engineers,
29 W. 39th Street,
New York, N. Y.

Dear Sir:

I take pleasure in transmitting herewith Transactions, Petroleum Development and Technology, 1931, containing 65 papers covering most of the newer developments in technical information on unit operation, petroleum engineering, research engineering, economics, and world production. These papers were presented at the two fall meetings, held in Tulsa, October 2 and 3, and Los Angeles, October 17, 1930, and the annual meeting, Feb. 17–19, 1931.

Study of unit operation was continued from last year. The production engineering sessions were particularly interested in flowing wells, and in the effect of natural water-flooding and control of water in oil fields. Economics sessions were concerned mostly with the economic adjustments necessary to reduce the depressing effect of overproduction. The world production review presented briefly the situation in world sources of petroleum, the significance of new developments, and what may be expected in the future, particularly during the coming year.

I take this opportunity to express the appreciation of the Petroleum Division to the officers of the Institute, and especially to the staff at headquarters, for many valuable suggestions on the programs and assistance in conducting the meetings. I desire to express my personal appreciation of the whole-hearted cooperation and individual work of my fellow officers of the Petroleum Division, which has resulted in bringing together this volume of technical papers. So long as such interest and spirit of cooperation exist the Petroleum Division cannot help but continue to increase in value to the members and to the industry which they represent.

Respectfully submitted,
Charles V. Millikan, *Chairman*,
Petroleum Division, 1930

PLANS OF PETROLEUM DIVISION FOR 1931

H. Foster Bain, Secretary,
American Institute of Mining and Metallurgical Engineers,
New York, N. Y.

Dear Sir:

The Petroleum Division of the American Institute of Mining and Metallurgical Engineers is planning to hold three meetings during the year 1931–1932. The first will be in Southern California in September. For several years a meeting has been held in Tulsa just prior to the Petroleum Exposition in September or October, but as the Exposition will not be held this year, the second meeting will be held in Houston, Texas, October 2 and 3.

Topics pertaining to the more efficient utilization of the energy possessed by natural gas associated with and dissolved in the oil will be discussed at the meetings in Southern California and Texas. It is hoped that papers may be secured on subjects pertaining to bottom-hole pressures, the use of bottom-hole beans, the flow through tubing, etc. The general subject of proration and its relation to more economical production and greater recovery of oil is another subject for discussion. New developments or thoughts pertaining to unit operation will be taken up if papers can be secured.

The meeting in New York will cover a wider range of subjects than the fall meetings and will include such topics as production engineering, engineering education, engineering research, unit operation, domestic production review, general production review and economics. The annual summaries of production engineering, production, economics and refining will be presented at the evening session following the customary Petroleum Division banquet.

If manuscripts can be obtained prior to the meetings they will be printed and a few copies sent out for the purpose of securing discussion. If possible, more time will be given for discussion of papers pertaining to engineering problems of especial interest.

Respectfully submitted,
C. E. Beecher, *Chairman,*
Petroleum Division, 1931.

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Chapter I. Unit Operation

Stabilizing Influences

By Earl Oliver,* Ponca City, Okla.

(New York Meeting, February, 1931)

Some two years ago the Petroleum Division of the A. I. M. E. organized a special study of unit operation. That method of handling oil pools had been urged as the remedy that would save the United States petroleum industry from the crisis that even then loomed as more than a small cloud on the horizon. Today it is only one of several remedies vigorously advocated.

Proration, regulation of imports, unit operation, constructive marketing and interstate compacts all have their earnest proponents, but the advocates of each have been disposed to look with indifference on the other respective proposals, with the result that none has had united support. Meanwhile the industry has drifted rapidly toward a serious crisis, the imminence of which in itself may bring the solution. The gravity of the situation tends to force study of the merits of proposals that a short time previously were brushed aside as impractical; and to the surprise of most of us we now find merit where previously we thought none existed.

Irrespective of what might have been the result had any single proposal being adopted years ago, it is now apparent that under present conditions no one of the remedies—unit operation, proration, regulation of imports or constructive marketing—standing alone would be of much benefit. On the other hand, it is becoming evident that a well balanced program comprising all four of these remedies might save the United States petroleum industry; also that some such comprehensive program might be necessary to save it.

It is even becoming evident that the despised interstate compact might be an appropriate type of machinery in which to group and coordinate all these remedies. We have progressed beyond the belief that either the industry or the government working alone can correct the situation, and have arrived at the more healthy realization that the task will require most sympathetic cooperation between government and industry, backed by an equally sympathetic public understanding.

If we were functioning under a Mussolini or a Stalin, stabilizing the petroleum industry would be a much simpler task. However, in the

* Chairman, A. I. M. E. Committee on Unit Operation of Oil Pools.

United States we prefer to bring about these changes by a certain due process of law in which individual rights are carefully scrutinized and attention is given to avoiding conflict with other major public policies. This is a slower and sometimes a more difficult method than that used by the Fascists and Soviets. But it is also less painful and, we believe, is usually more satisfactory in permanent results. It is the lawyer who guides us through the mazes of due legal process.

Consequently, proponents of these several remedies, all designed to stabilize the petroleum industry, will more effectively promote the special panacea they chance to advocate by determining what is its relative place in the major program of which it forms a part, how it should be coordinated with other methods in that major program, and finally, what is the due process of law by which it should be established. This applies with equal force to unit operation and to the several other parts of the program.

Engineers can formulate scientific methods but the lawyer alone, under our American system, is qualified to incorporate them into the political and economic structure. It is clear that the chaotic condition of the petroleum industry today is due to the fact that the scientist is making advances in technique more rapidly than the lawyer can arrange for their orderly assimilation. It follows, therefore, that the lawyer and the engineer must work closely together in the complicated stabilization efforts if the American petroleum industry is to recover from the economic ills that now burden it. To that end today's unit operation program is given over to legal discussions in which representatives of a sister profession have kindly consented to address us regarding our joint problem. The facts that these gentlemen present must become more extensively understood and accepted by oil men and legislators alike and incorporated generally in oil-field practice before a substantial recovery may be expected in the petroleum industry.

Compulsory Unit Operation of Oil Pools

By W. P. Z. German,* Tulsa, Okla.

(New York Meeting, February, 1931)

Some attention should be given to definitions. The term "unit operation" may have at least two meanings. One meaning is the merging of titles and the development and operation of the unitized area, as if it were one tract of land held under a single oil and gas lease, according to a definite program intended to accomplish a maximum recovery from the pool as a whole at a minimum of cost. It is incomplete when the royalty owners do not also merge their titles to their oil and gas rights in the area, and is complete when they do. The other meaning is not accompanied by any merger of titles, but the development and operation of the area is in accordance, as nearly as reasonably practicable, with such a program. This second conception may be nothing more than a cooperative development and operation plan, but in this paper it is regarded as more than that. If there cannot be unit operation without a merger of titles, it would seem that the state cannot require unit operation, for it cannot require a merging of titles; but if it may consist in requiring each and all of the leaseholders to develop and operate or to submit to a development and operation according to some such common plan as is referred to above without at the same time requiring a merger of titles, it would seem that unit operation may be required by the state. Whether the states have this power is the subject to be herein considered. If the state can so bind the several lessees, it also can so bind the several lessors.

The writer does not know what would be an ideal plan for the development and operation of a pool; but it takes into account the fact that the accumulation of gas and oil is not uniform throughout the formation; that often free gas, highly compressed, occupies the upper portions of the reservoir, the oil with compressed gas in solution coming next in order; that at places oil is not overlain by free gas, and sometimes there are peaks where free gas is not immediately underlain by any oil; and the fact that these substances are held under a uniformly distributed pressure, generally referred to as "rock pressure." It also recognizes that the most efficient utilization of this naturally existing reservoir pressure in the recovery of the oil requires that there be no operation of wells completed into areas where gas only has accumulated, for this diminishes the

* General Attorney, Skelly Oil Co.

pressure, withdraws gas which could migrate to oil-bearing areas, and draws gas out of solution with oil, all to the detriment of oil recovery; and that there shall be only an operation of wells which are completed into oil-saturated areas. The gas would be thus recovered along with the recovery of the oil, and at the same time there is a most beneficial use of the rock pressure. Some believe that it is preferable that the oil lowest down the slope shall be extracted first. The superiority of unit operation over proration as we know it today is obvious. Among other differences, proration ignores an orderly development of a field, whereas unit operation recognizes and enforces it.

Police Power

The authority of a state to intervene and correct evils of the type we are discussing is called its "police power." This power of a state is vested in its legislature, and is to be manifested by the enactment of laws. Blackstone defines this power as the due regulation of the domestic order of the kingdom whereby the inhabitants of a state are bound to conform their behavior to the rules of propriety, good neighborhood, and good manners, and to be decent, industrious and inoffensive in their respective stations. Cooley says that it includes regulations by which the state seeks to establish for the intercourse of citizens with citizens those rules of good manners and good neighborhood which are calculated to prevent a conflict of rights, and to insure to each the uninterrupted enjoyment of his own so far as is reasonably consistent with a like enjoyment of rights by others. It has been said that all police power rests upon the common law maxim that every person shall be required so to use his property as not to injure the rights of others.

There are at least four conditions which obtain in the oil industry which might well justify an exercise of the police power of the state, if the power extends that far, to enforce the unit operation of oil fields or something analogous to it, whenever it cannot be had by agreement. These are:

First: The existence in oil fields of so many separate individual holdings, in small tracts of land;

Second: The migratory nature of oil and gas deposits, and the presence of pressure with them in the reservoir beneath; the tremendous value of this pressure, whenever it is placed under proper control, in the recovery of the oil and the inestimable harm that can grow out of its wastage;

Third: The desire of the individual lessee to obtain through wells on his lease and to keep all that he can get of the oil and gas beneath, when and as fast as he may choose, without regard to the situation of his neighbors, and without regard to market conditions; which, less politely stated, may be termed human greed; and

Fourth: Distrust.

Due particularly to the third and fourth of these conditions, widespread unit operation by agreement seems to be difficult, if not impossible, of accomplishment. And yet, an ordinary conception of right and wrong should satisfy everyone that each land proprietor in a pool is entitled to a fair proportionate part, and no more, of the recoverable reservoir content if at the same time he can be required to share on a like basis in the cost of its recovery.

The state is interested in two things, namely:

1. The conservation of the irreplaceable oil and gas deposits within its boundaries, and in their production without waste, either underground or surface, for the use and enjoyment of its inhabitants as and when needed by them, and this includes future generations. This interest is to be manifested by an exercise of the police power. There are two ways in which the citizens of the state may use and enjoy these substances. One consists in the profitable extraction thereof from the ground by landowners within the state, whose lands are located in the oil and gas fields, and their profitable sale, and the profitable refining of such of the oil so extracted as may be utilized in refineries located within the state; and the other is the use of the gas for domestic and industrial purposes and of the by-products of the oil in motor vehicles, and of both substances in various and sundry other ways by the inhabitants of the state. Thus the state is interested in the recovery of the maximum amount of these substances from each and every pool within its borders at a minimum of cost, and also that their production from time to time shall bear a reasonable relation to reasonable market demands.

2. The state is equally interested in the protection of the several proprietors and their lessees of lands located within the oil pools within its boundaries against the extraction or the dissipation and waste by any one or more of them of a disproportionate part of the oil and gas within the reservoir and in the accomplishment of a fair and equitable distribution among all of them of the recoverable oil and gas therefrom. It is as much a part of the duty of the state thus to protect the several proprietors in a pool as it is to protect the general public in the conservation of these natural resources. This interest is also to be manifested by an exercise of the police power.

Court Decisions

The courts have held that *in the absence of legislative restraint* the owner of land or his lessee may produce through his wells all of the oil and gas that he is able to extract from the reservoir beneath without regard to where in the reservoir he may draw from and that he becomes the absolute owner of all thereof that he reduces to possession. Until the legislature has provided that he shall not do so, his neighbors cannot enjoin him

from so doing, nor can they recover damages on account thereof. Their sole remedy against drainage is the development and operation of their lands. These are the holdings of the courts both in states which have adopted the rule of ownership in place and those which deny ownership in place. The effect of these rules is to encourage rather than retard practices which lead to confusion, wasteful haste, duplication of development and operation, undue dissipation of gas pressure and a volume of production in no sense related to market demands. They are the antitheses of conservation, both physical and economic; but the fault does not lie with the courts, for the same courts have conceded the legislative power to alter these rules. Furthermore, the same courts have gone further and announced another rule which we who are interested in unit operation will find very helpful. They have held that oil and gas while in the ground belong to the owner of the land in which for the time being they lie and that the title thereto remains in him so long as they remain in his land; they recognize the migratory and fugacious character of these substances but concede that so long as they are positioned beneath the surface of the land of one owner they belong to such owner and not to anyone else, subject, it is true, to his loss of his title by no act of his own, without his consent and even without his knowledge, for they concede that whenever they escape and go into the land of another the title of the former owner disappears and becomes that of the landowner into whose land their new position has been taken. This is helpful because whenever we go back of the time when production is first had in a field, we are enabled to visualize the original right of each landowner therein as compared with that of all others. For all practical purposes no migration occurs until by the hand of man the formation is punctured and production commenced. Before there is any disturbance of the location of these substances in the reservoir, that is, prior to the time when the first well is drilled and operated, each land proprietor stands as the owner of, or, to say the least of it, equitably entitled to that quantity of the oil and gas which lies beneath the surface of his land. If it is practicable by some method of testing wells drilled at selected sites, examination of sand cores, etc., to estimate within reasonable bounds, not at all with mathematical accuracy, the fertility of that portion of the producing formation which lies under the surface of the land of each proprietor, then it is possible to appraise quantitatively the rights of each to a distribution of the recovered oil and gas; or, there may be other standards for determining each man's fair part of what may be recovered. These are problems for the petroleum engineer. These suggestions anticipate unit operation with the inception of development; but, if it should come afterwards, the then existing underground status (by which all concerned would doubtless find themselves bound) might be ascertainable by similar methods.

The United States Supreme Court in the case of *Ohio Oil Co.* v. *Indiana,* 177 U. S. 190, 44 L.ed. 729, decided in 1900, gave to us the guiding principle when it said that from the peculiar nature of the right of each surface proprietor in a field and the objects upon which it is to be exerted, *the legislative power can be manifested for the purpose of protecting all the collective owners by securing a just distribution to arise from the enjoyment by them of their privilege to reduce to possession.* It made this guiding rule clearer when in the case of *Walls* v. *Midland Carbon Co.,* 254 U. S. 300, 65 L.ed. 276, it said that "before the event occurs, indeed, in prevention of it, the state may interpose its power to prevent a waste or a disproportionate use of either oil or gas by a particular owner in order to conserve the equal rights of other owners and advance the public interest," and stated that in the Ohio Oil Co. case it had been adjudged that the use by one owner of the surface affected the use of other owners and an excessive use of one diminished the use of others, and that hence the power of the state can be manifested for the purpose of protecting all by securing a *just distribution* to arise from the enjoyment by them of their privilege to reduce to possession.

It has been said that "the ultimate aim of proration and of unit operation should be to recover for each leaseholder only that oil which originally underlay his property; that proration and unit operation will do away forever with legalized piracy which says that the oil belongs to the man that reduces it to possession." Proration is a helpful remedy; but unit operation is a cure, for it can more nearly attain a fair distribution as well as prevent underground waste.

Some states have passed oil and gas conservation laws. These are usually directed primarily against waste in the interest of the general public. Some of them are also aimed directly at the safeguarding of individual rights. Great progress has been made in recent years in the science of recovering, and that of conserving, oil and gas, *including the discovery of the inestimable value of a properly controlled use of reservoir pressure in the recovery of oil.* This discovery places a finger squarely on the reason for so much economic and underground waste. It furnishes a basis for an extension of the exercise of the legislative power to points further than it has ever gone, or, perhaps, in the case of some states, for the exercise by administrative agencies under existing laws of authority not previously undertaken. If proper use is made of this discovery, the public and the producer are equally protected.

Power to Require Unit Operation

While the state cannot compel a merger of titles, it seems to me to follow clearly, from the decisions of the United States Supreme Court already referred to and other cases presently to be reviewed, that the state has the power to require unit operation.

Proration has been sustained as constitutionally valid in Oklahoma by its Supreme Court (292 Pac. 841) and in an unreported opinion by a three-judge Federal court; by the Supreme Court of California (294 Pac. 717) and by the District Court of Travis County, Texas. The decisions in these cases are in point, but other decisions bear more directly upon compulsory unit operation.

In the first place, each proprietor's constitutional right to enjoy his own property is satisfied when there is delivered to him his share of the production wholly without regard to whether this production comes out of the ground through wells drilled on his own land or those drilled on the lands of others. If the oil and gas in the ground is not a common fund analogous to accidentally confused goods (12 Corpus Juris 492), but is owned in place, still, since they are migratory and when the pool is operated easily become confused, the rule governing accidental confusion of goods—that each is at least entitled to his aliquot part of the whole—is fairly applicable here. Each owner should, of course, in any event, be required to pay the cost of the recovery of his part.

A case directly in point here is that of *Marrs* v. *City of Oxford*, decided in 1928 by the United States District Court in Kansas, and reported in 24 Fed. (2) 541, and decided on appeal by the United States Circuit Court of Appeals for the Eighth Circuit, whose opinion is reported in 32 Fed. (2) 134. An oil field encroached upon the city of Oxford, Kans., and was proved to underlie a considerable part of the residential portion of the city. The city council passed an ordinance prohibiting the drilling of more than one well in a city block regardless of the fact that it was known that there were many separate land proprietors therein. A permit for the drilling of such well was required to be obtained and the ordinance provided that all of the several proprietors or their lessees in each block should have the privilege of enjoying shares in the production from the one well which was allowed to be drilled, upon payment of their respective proportionate parts of the cost and expense attending the drilling and operation thereof; and it provided that one-eighth of the production should be divided among the lessors of the leased lots without regard to cost and expense. A lot owner who had not leased his lot in a block in which a permit to drill a well had been granted to the lessee of another lot; a lessor of another lessee in the same block, and the last-mentioned lessee filed suits in the United States Court in Kansas, attacking the validity of this ordinance on the ground that it deprived them of rights guaranteed by the Fourteenth Amendment to the Constitution of the United States. Their contentions were denied and the ordinance was sustained by both the trial court and the circuit court of appeals.

It is obvious that in effect the provisions of said ordinance enforced the unit operation of each city block. Although there were several lot owners, but one well could be drilled within the block, and for the

drilling thereof a permit had to be obtained, and, upon fair conditions relating to the costs, the owners of all of the other lots and/or their lessees could and were to be allowed to share in the production from the one well. The distinction between this plan, on the one hand, and the unit operation by agreement of a like area, on the other, is that in the case of the ordinance there is no absolute obligation to pay any part of the cost of drilling the well, and the right to share in the production is made contingent upon actually sharing in the costs; whereas, in the case of agreed unit operation there is an absolute obligation to pay a prescribed share of the cost of development and operation, and also an absolute right to share in the production upon a prescribed basis. In the former, both landowners and their lessees were bound, for it was a police regulation, whereas, in the latter, if the royalty owners have not also agreed, they are not bound.

Having in mind the provisions of said ordinance, let us take particular note of what the United States Circuit Court of Appeals said about it. That court, after having sustained the validity of the ordinance upon the ground that it tended to protect the health and comfort of the residents of the city and their property from fire hazards, proceeded to add:

But looking to the substance of things, as equity does, what are the rights of plaintiffs that will be encroached upon or denied to them by the enforcement of this ordinance? It is not the mere right to drill a well on one or two lots at great cost and stop with that, or to take the proportionate part of the oil and gas in the pool that might be said to lie under or be fairly attributed to those lots. The obvious purpose was to reach the pool as quickly as possible and take all of the oil and gas obtainable before others could get it, thus seriously encroaching upon and probably destroying the same rights of adjoining lot owners. If one or more lot owners have given a lease for which no permit is obtainable their lessee may join a lessee who has a permit in the same block on terms that are fair to both lessor and lessee. If a lot owner has not given a lease he is protected by the asking in a fair porportion of the mineral produced by a permittee. The regulations make every effort to protect, rather than to destroy rights. They extend equal opportunity to all who have an interest and eliminate the race between those having equal rights in a common source of wealth, so that some may not take all and leave others with nothing. Under the law in Kansas there is no property in oil and gas, because of their migratory nature, until they have been captured, though each surface owner may take without limit, unless lawfully restrained. *Phillips* v. *Springfield Crude Oil Co.*, 76 Kan. 783, 92 P. 1119; *National Supply Co.* v. *McLeod,* 116 Kan. 477, 227 P. 350. This is the rule also in Pennsylvania and Indiana. The nature of this right was fully discussed and defined in *Ohio Oil Co.* v. *Indiana,* 177 U. S. 190, 20 S. Ct. 576, 44 L.Ed. 729. The court in that case, after accepting the general practice as a settled principle, that every owner of the surface within a gas or oil field might prosecute his efforts and reduce to his possession if possible all of the deposits without violating the rights of other surface owners, in the absence of regulations to the contrary, said:

"But there is a co-equal right in them all to take from a common source of supply, the two substances which in the nature of things are united, though separate. It follows from the essence of their right and from the situation of the things, as to which it can be exerted, that the use by one of his power to seek to convert a part of the com-

mon fund to actual possession may result in an undue proportion being attributed to one of the possessors of the right, to the detriment of the others, or by waste by one or more, to the annihilation of the rights of the remainder. Hence it is that the legislative power, from the peculiar nature of the right and the objects upon which it is to be exerted, can be manifested for the purpose of protecting all the collective owners, by securing a just distribution, to arise from the enjoyment by them, of their privilege to reduce to possession, and to reach the like end by preventing waste."

If this right in each and all of the surface owners can be thus restrained and its exercise regulated by a law of the state enacted for the purpose, how can it be held that a valid police regulation, which incidentally and in caution embodies the same restraint and regulation, can be made the basis of a claim that plaintiffs have a right to take all of it, and any restraint of that right violates constitutional guaranties? The basis of a statute, suggested in the Indiana case, is the governmental power to equally protect each surface owner in his right to a common fund.

Thus we see that what is in effect, if not in reality, an enforced unit operation of a city block has been sustained not only upon the ground that it protected the health and comfort of the inhabitants of the city and diminished the fire hazard to their property, but also upon the added ground that by the recovery through one well in a block of oil for all of the several lot owners within it, none was deprived of any constitutional right to drill upon his own property and to produce his oil through his own well, since each was extended the opportunity upon fair terms, to receive, by the asking, a fair share of the production; and the plan eliminated the costly race between those having equal rights.

The United States Supreme Court denied a petition for a writ of certiorari to bring the case there for its review, and thus by indirection announced that it found no serious fault, if any at all, with the decision below.

Territorial Extent of Application of Principle of Regulation

If such a system for the development and operation of a city block, an enforced unit operation thereof, wherein there are a large number of separate lot owners, does not deprive any lot owner of any constitutional right, then why may not a system for the unit operation of an area greater than the size of a city block, such as one or more sections of land or the whole of an oil field, be lawfully adopted and enforced? The only difference between the two lies in the territorial extent of the application of the same principle of regulation.

Neither District Judge McDermott nor Circuit Judge Lewis founded his sustenance of the constitutional validity of the ordinance upon the sole ground that it protected to some extent the health, comfort and property of the inhabitants of the city of Oxford. They each, and particularly Judge McDermott, spoke of the economic waste in the drilling of unnecessary wells which was prevented by the ordinance; and both of them regarded the plan as coming within the holding in the

Ohio Oil Co. case with reference to the power of the legislature to accomplish proportionality of taking from a pool. So it cannot in my judgment be reasonably or successfully contended that the courts would not have sustained the ordinance had it not been for the presence of homes and families within the area affected by it. Nothing is made clearer than that if the same town lot situation had existed anywhere else, and had been unaccompanied by the presence of persons or residences, a regulation like that which the ordinance contained, relating to the development of the area, would have been sustained upon the same principle which lay at the foundation of the announcement in the Ohio Oil Co. case. If an equal opportunity, such as the Oxford ordinance afforded to every lot owner, should be extended to all the leaseholders within an entire oil field to receive, upon fair terms as to the expense, an interest in the production from prescribed and allowed wells in the field upon a basis of a fair apportionment of the production, and at the same time there should be eliminated the race between those having equal rights in the common source of wealth so that some may not take all and leave others with nothing or less than their share, who can say, in the light of this decision, that such a program applied to the field as a whole would operate to take from any leaseholder therein any of his constitutional rights? Let it be left to others to pass upon the practical wisdom of compelling such a complete pooling of a large oil field. There are operators in the Oklahoma City field who have almost prayed for some way to stop the waste of gas energy.

We have another interesting case. It arose in Texas. The commonly called 150-ft. rule issued by the Railroad Commission of that state and its enforcement is a step in the direction of a requirement of unit operation. The Texas statute provides that the Railroad Commission "is empowered to establish rules and regulations for the drilling of wells and preserving a record thereof" and makes it the duty of the Commission "to require such wells to be drilled in such a manner as to prevent injury to the adjoining property." The rule promulgated by the Commission provides that no well for oil or gas shall be drilled nearer than 300 ft. to any other completed or drilling well on the same or an adjoining tract of land and that no well shall be drilled nearer than 150 ft. to any property line, but it contains a proviso to the effect that the Commission, in order to prevent waste or to protect vested rights, may grant exceptions and permit drilling within shorter distances. The validity of this regulation and of a special order issued under the proviso were assailed in the case of *Oxford Oil Co.* v. *Atlantic Oil & Producing Co.* (D.C.E.D. Tex.) 16 Fed. (2) 639; (C.C.A. 5) 22 Fed. (2) 597. The Oxford Oil Co. owned an oil lease on a strip of ground 3160 ft. long, 56 ft. wide at one end and 36 ft. wide at the other, in the heart of a prolific oil field in Texas. It had planned to drill 10 wells on this narrow strip. They would have

been about 300 ft. apart and within about 25 ft. of adjoining large tracts held under lease by others. By an order the Commission limited the Oxford company to the drilling of four wells and specified where they must be located. By the order those wells were not evenly spaced; the first was 150 ft. south of the north line of the 3160-ft. tract, the second 913 ft. south of the first, the third 157 ft. south of the second, and the fourth 906 ft. south of the third, and this left 1064 ft. between the fourth well and the south line of the tract. The wells were drilled accordingly, and operated, and then the company sued the Atlantic Oil & Producing Co. and the members of the Commission and others for damages, claiming that it had been deprived of its right to drill wells on its leased land and thus was deprived of its property in violation of the Fourteenth Amendment to the Constitution of the United States. The Atlantic Oil & Producing Co. owned, developed and operated the adjoining large lease on one side and another company was likewise situated on the other side. Their wells were 150 ft. from property lines and did not match the Oxford company's wells. The Atlantic company had some part in procuring the special order on the Oxford company. Judge Atwell, in deciding the case in the trial court, stated that an oil well will drain lands around it for 150 ft. in every direction, and that the Oxford Oil Co. could not drill any well on its strip of land without draining the contiguous land, and that "if allowed to drill unsupervised, they would not only get all of the oil that was under their own land, but they would secure a large amount of property that belonged to others. They could not drill any well without this result." The court sustained the regulation and the order made under it upon reason and upon the authority of the Ohio Oil Co. case and other cases. In concluding, Judge Atwell said:

> I am convinced that the plaintiff's rights have not been violated and that the drillings allowed by the Commission were consonant with the plaintiff's ownership, rights of development, and enjoyment, and the preservation of the property rights of neighboring and contiguous owners.

The Circuit Court of Appeals, in affirming this holding, said, among other things, that

> The right of a state to so regulate the drilling of wells for oil and gas as to conserve the rights of adjoining owners is too well settled to admit of serious controversy. . . . It was within the power of the Legislature to lay down a general rule for the protection of the mineral rights of the owners of adjoining lands, and to leave the details of enforcing that rule to an administrative agency or board.

The United States Supreme Court refused to grant a writ of certiorari in that case. The decision in this case is particularly significant for two reasons: (1) A fair distribution of the recoverable oil in the area of the lease among the holders of leases therein was the one and sole purpose

of the order. No waste above or under ground was involved; and (2) Texas is one of the few states wherein the courts have held that the owner of land owns the oil and gas in place. Through the allowed wells, the Oxford company would draw oil from its neighbors, and through their wells, its neighbors would draw oil from certain unprotected parts of the Oxford company's strip. Judge Atwell mentioned the fact that under the decisions of the Texas courts the landowner owns the oil and gas in place, and held that if the difference between the rule in that state and the opposite rule on that subject in Indiana (whose statute was involved in the Ohio Oil Co. decision) has any bearing upon the problem under discussion "it tends to add a stiffening to the reason for sustaining the Texas regulation as a proper exercise of its police power." He clearly meant that the regulation and the particular order tended to accomplish proportionality of taking, and that if thereby the Oxford company acquired, under the circumstances, an amount of oil equal to that in place under its land, it was immaterial where in the reservoir it came from.

If the power exists, and particularly in a state where, as in Texas, the owner of real property owns the oil and gas in place, to require a particular location or spacing of wells in a small limited portion of the area of a large oil field in order to accomplish a fair distribution of the production among a few producers in such limited area, then it necessarily follows that, for the same reasons and upon the same grounds, the power exists (and if circumstances require, it may be exercised) to regulate the spacing and location of wells throughout the entirety of any such field in order to accomplish a fair distribution among all of the producers therein. If the legislature, or an administrative body acting under its authority, has the power to regulate the spacing of wells of one operator for the protection of his neighbors, it would seem necessarily to follow that it has the power to regulate in like manner all the other operators in the field in carrying out a comprehensive plan of conservation and of fair distribution of the reservoir content among them all.

It will not do to say that if the property boundary lines in a field happen to be so regularly fixed as that wells would be located in accordance with the prevailing practice of the industry, that is, one well to each 10 acres, and that if the field were developed according to custom, no well would be nearer to a property line than 300 ft., the power of regulation would not exist. There nevertheless would still obtain the competitive struggle, confusion, wasteful haste and undue dissipation of gas energy. In the absence of either voluntary or enforced orderly and regulated operation of the field, no fair distribution among the several leaseholders of the recoverable oil from the reservoir would be possible. The race for advantage would still obtain. There would be disproportionate takings and disproportionate and unfair use made of the commonly owned gas energy.

I have not been able to study sufficiently the gas-oil ratio statute of California, nor the decisions of the courts of that state (294 Pac. 717; 293 Pac. 899) sustaining its constitutional validity, to make it safe to review them. Petroleum engineers will, I think, give credit to that state and its courts for having made the first substantial legislative and judicial direct recognition of the presence of gas energy in subsurface oil zones and its importance in the recovery of the oil, and as the first to take affirmative steps to prevent the waste and to require the utilization of this energy. The Oklahoma Corporation Commission and perhaps the Texas Railroad Commission have recognized this to some extent in proration orders. If a state can require what the California statute does, then there appears no good reason why it could not require the conservation and use of this energy by a type of development and operation such as is the subject of discussion in this paper.

New Application of Ancient Principle of Law

The principle underlying the Ohio Oil Co. case and kindred decisions is not new. It is older than our Government. It is embodied in the ancient maxim of the common law that everyone must so use his own property as not to injure the rights of others, which lies at the base of a proper exercise of the police power. It happens that this principle has been but recently applied to conditions in this comparatively young and now rapidly growing industry.

Many years ago it was stated by the courts that the Government has the power to prescribe regulations for the better and more economical management of property *of persons whose properties adjoin*, or which, for some other reasons, can be better managed or improved by some joint operation. This early announcement was quoted by the United States Supreme Court in *Wurts* v. *Hoagland*, 114 U. S. 606, 29 L.ed. 229. It was long ago held by courts, as is shown by quotations in the Wurts case, that where there are *adjoining lands held by various owners in severalty* and which, *by reason of the peculiar natural condition* of the whole tract, cannot be improved or enjoyed by any of them without the concurrence of all, there is presented a condition where the power of the legislature may be exerted to establish regulations whereby all may be compelled to submit to proceedings whereby they may be improved or enjoyed, and to contribute, in proportion to the benefits enjoyed by each, to the expense of the steps taken to accomplish such improvement or enjoyment.

This principle has been applied in drainage cases where, in order that the several owners of land located in an area which is subject to overflows or wherein swamps exist, and, as a result, the establishment of drains is necessary to the better enjoyment by the several owners of their

respective tracts within the area. It has long been applied to party walls, partition fences and other conditions. Its applications to a variety of situations furnishes to us something which the Supreme Court did not suggest in the Ohio Oil Co. case as a means for accomplishment of an enforced fair and equitable distribution of the oil and gas reservoir content among the several proprietors whose lands lie within the pool.

Regulation in Drainage Cases

The establishment of drainage districts by or under the legislative authority is an exercise of the police power of the state. While drains cannot be provided for purely private purposes, the public benefit required need not be a use or benefit accruing to the whole public or any large portion of it, and if the public purpose is kept in view, the fact that private interests will also be promoted is immaterial. Statutes authorizing the reclamation of swamp or agricultural lands by drainage are held to be valid independently of any effects upon the public health, if they tend to the general advantage or prosperity of the community (19 C. J. 610). The power to construct drains is a special authority given for a particular purpose and may be conferred upon any person or body upon which the legislature may see fit to confer it (19 C. J. 611). A reclamation statute creating reclamation districts and providing that those who are interested in the land and must pay for the improvements shall determine by an election whether the improvement shall be made, was sustained in California (48 Pac. 1016). The Indiana Supreme Court held (99 N.E. 742) that public ditches, like public highways, are subjects of the state's control, and it may delegate to interested persons the power of initiative and declare the extent of jurisdiction.

In *Wurts* v. *Hoagland*, cited above, an attack was made upon an act of the Legislature of New Jersey which provided for the establishment of drainage districts for the reclamation and improvement of swamp or overflowed lands. There were certain provisions of the law with reference to the payment of the expense of construction and maintenance of the system, one of which was that the cost and expense should be distributed and assessed to the several properties in proportion to the benefit derived by each from the drainage. A landowner in a drainage district established under this statute asserted that its operation deprived him of his property without due process of law. It requires no stretch of the imagination to look upon this statute as an enforced unitized drainage system. The state courts sustained the law. In reviewing the case on writ of error, the Supreme Court of the United States pointed out that laws authorizing drainage of tracts of swamp and lowlands by commissioners appointed upon proceedings instituted by some of the owners of the lands, and the assessment of the whole expense of the work upon all the lands within the area benefited, had long existed in the State of

New Jersey and in many other states; and it quoted approvingly from an early decision of the New Jersey Supreme Court, this language:

> Laws for the drainage or embanking of low grounds, and to provide for the expense, for the mere benefit of the proprietors, without reference to the public good, are to be classed, not under the taxing, but the police power of the government.

It quoted from another decision of the New Jersey court, wherein it was held that power exists in the local government to prescribe public regulations *for the better and more economical management of the property of persons whose properties adjoin or which for some other reason can be better managed and improved by joint operation,* such as the power of regulating the building of party walls, the making and maintaining of partition fences and ditches, the construction of ditches and sewers for the draining of uplands and marshes, which can more advantageously be drained by a common sewer or ditch; *and that this is a well-known legislative power, recognized and treated by all the courts and writers upon law* throughout the civilized world; a branch of legislative power exercised both before and since the Revolution and before and since the adoption of the present Constitution, and repeatedly recognized by the courts of New Jersey. In that case, the New Jersey court is quoted as having held that the principle of all these laws is to make an improvement common to all concerned and at the expense of all; that in none of the works established under such laws is the owner divested of his fee, and for all purposes the title of the land remained in the owner. The Supreme Court, after having reviewed these and other cases, then said:

> This review of the cases clearly shows that general laws for the drainage of large tracts of swamps and lowlands upon proceedings instituted by some of the proprietors of the lands to compel all to contribute to the expense of their drainage, have been maintained by the courts of New Jersey (without reference to the power of taking private property for the public use under the right of eminent domain, or to the power of suppressing a nuisance dangerous to the public health) as a just and constitutional exercise of the power of the legislature to establish regulations by which adjoining lands, held by various owners in severalty, and in the improvement of which all have a common interest, but which, by reason of the peculiar natural conditions of the whole tract, cannot be improved or enjoyed by any of them without the concurrence of all, may be reclaimed and made useful to all at their joint expense.

Numerous cases sustaining the same principle might be cited, but lack of time forbids.

Analogy between Regulation of Drainage and Enforced Unit Operation

The analogy between the drainage cases and a requirement for the unit operation of oil pools seems to be clear. In the former, by reason of the peculiar natural conditions, the whole area cannot be improved or enjoyed to its full extent without the concurrence of all, and since all will not concur, they may be compelled to conform to a plan best calcu-

lated, on the whole, to secure and promote both the common interest of all and the individual interest of each of them. This same thing is manifestly true in the case of the oil pool. Oil and its accompanying gas are migratory and fugacious and will pass from the land of one proprietor to that of another, so that one, either by waste or a disproportionate use thereof, has it in his power to seriously injure the other's and even to annihilate the rights of the others, and hence each may be compelled to yield, not his title, but some control and dominion in the interest of the common good of all. By reason of the peculiar nature of these substances and the peculiar natural conditions, the rights of the several proprietors in the oil pool to take from the common source of supply cannot all be protected (in the absence of the concurrence of all) unless the state, in the exercise of its legislative power, secures a just distribution among all to arise from the enjoyment by all of their privilege to reduce to possession. The soundness of these statements, which are but paraphrases of the statements in the Ohio Oil Co. case, is greatly strengthened by the recent discovery of gas energy in oil pools and its function in the recovery of oil. Such an oil statute would be founded and predicated upon the same principle upon which the drainage acts are predicated. It would not be something new in the law, but only a new application of an old and well settled principle. These references to laws relating to drainage districts suggest that the legislature of a state might authorize the creation of oil and gas conservation districts, with power in the owners of leases upon lands within an oil field or an area which may be thought to be underlain by oil or gas, to organize such a district to be operated on the unit plan; all with the view to accomplishing two purposes—*first,* the prevention of the waste of oil and/or gas in the area for the general benefit of the public at large and to conserve it for use as and when needed by the public, and, *second,* to bring about a fair distribution of the content of the reservoir among the several land proprietors and to protect each against the extraction by any of a disproportionate part thereof.

In practice it would doubtless be almost universally true that the owners of leases upon a considerable portion of the acreage would agree to the unitization of their lands and would be in a position to vote or petition for the establishment of an oil conservation district to be operated with a view to accomplishing the purposes above enumerated, and thereby force into the plan those unwilling to join it. Having been established pursuant to legislative enactment, royalty owners would be likewise bound. The area of the pool might, and doubtless, in most instances, would be unknown at the beginning of development; but it could be approximated. A particular area could be originally brought into the plan with the understanding that as development progressed, its boundaries could be extended; and, if land brought in proved to be outside the

pool, it could be later excluded. We find that in the case of drainage districts it is not an uncommon thing for lands which are brought in to be later excluded because found not to be benefited, and, also, that lands are often added or annexed to the district which it is later discovered will be benefited by it. (*Hauck* v. *Little River Drainage District*, 239 U. S. 254, 60 L.ed. 266; 19 C.J. 621–622.)

Police Power Should Safeguard General Prosperity

Is the saving to the producers in cost of recovery a meritorious consideration from a legal standpoint? The answer must be in the affirmative. The police power of the state is not limited to measures for the protection of the health, safety and comfort of its citizens. It extends also to the promotion of general prosperity, a fact referred to in strong terms by the California Supreme Court in the gas-oil ratio case (294 Pac. 717). The Idaho sheep-herding statute was sustained upon the ground that it promoted the prosperity and general welfare of the state and its inhabitants (*Bacon* v. *Walker*, 200 U. S. 561). In the City of Oxford case, the trial court, speaking through Judge McDermott, who later became a circuit judge in the newly created Tenth Circuit Court of Appeals, made a particular point here. He said:

"Without any attempt to define police power, it is sufficient to say that the police power is not limited to the protection of the health, peace and morals of the community. It has been said to extend to acts that 'increase the industries of the state, develop its resources, and add to its wealth and prosperity' (*Barbier* v. *Connolly*, 113 U. S. 27, 5 S.Ct. 357, 28 L.ed. 923), and to 'promote the public convenience and the general prosperity' (*C. B. & V. Ry.* v. *People*, 200 U. S. 561, 26 S.Ct. 341, 50 L.ed. 596, 4 Ann. Cas. 1175)."

Referring to zoning ordinances, and particularly to the ordinance involved in the case of *Euclid* v. *Ambler Realty Co.*, 272 U. S. 365, Judge McDermott said that

> The ordinance was sustained on the broad ground that one can be compelled by law to use his own so as not to injure another.

Later, he said that

> The argument most generally used in support of zoning ordinances is that of the stabilization of property values, and giving some assurance to the public that, if property is purchased in a residential district, its value as such will be preserved, is probably the most cogent reason back of zoning ordinances. That reason exists in the case at bar. An ordinance which affords some protection to the public generally from the waste of town lot drilling, and gives some assurance to owners of real estate that the oil under their property may be economically recovered, is within the police power. An ordinance that makes it impossible for a diligent or fortunate lot owner to drain the oil from his neighbor's lots, to his own exclusive use; an ordinance which makes it impossible for an owner of property in a block to prevent any recovery of oil on other parts of the block—is valid.

We have the question as to whether the imposition by a legislature of such a regulation as we are discussing would constitute an unreasonable restraint. One limitation upon the police power is that the regulation must not be unreasonable or arbitrary; otherwise, the courts will strike it down as a taking of property. It therefore becomes necessary that we make sure of the soundness of our position from a fact standpoint. However, in the Ohio Oil Co. case, that company was unable profitably to operate its oil wells unless it were allowed to produce at the same time the gas, and, it had no market for the gas. The court nevertheless sustained the law prohibiting a waste of the gas. The case of *Walls* v. *Midland Carbon Co.*, 254 U. S. 300, 65 L.ed. 276, presents a still stronger case which those who are interested may desire to read. In the California case, the operation of a certain well was enjoined until more efficient methods should be employed to conserve the gas (294 Pac. 717, 726).

In the Texas 150-ft. rule case there was a limitation placed upon the otherwise existing right to drill as many wells as the lease owner desired, and, while the reasonableness of the order was not raised in the suit, yet the court took account of the area from which the lease owner would draw oil through its wells, and although it was not at all apparent that the particular number of wells allowed to be drilled, when considered in connection with the wells on adjoining lands, enabled each leaseholder in the particular area to extract from the reservoir his fair share based upon any sort of mathematical calculation, yet, the court dealt to no small extent with the reasonableness of the limitation on the Oxford Oil Co. under the circumstances. Surely, if the Texas order, which so far failed of perfection, was not unreasonable or arbitrary, a regulation which more nearly approaches a distribution among the surface owners upon a basis which, by mathematical calculation, is approximately fair, could not be said to be unreasonable or arbitrary. The same thing may be said of the City of Oxford, Kansas, case. But the point is that any enforced unit operation plan must not be unreasonable; otherwise, it will be void.

The police power, if exercised, can close the door to the desire of your neighbor to gain possession of your oil and gas deposits. It can remove from your neighbor his fear that you will gain possession of his. The police power, if exercised, can dispense with the prevailing wasteful cost of capturing these substances. It can dispense with the practice of skimming the cream off of flush fields and leaving the bulk of the deposits to be possessed only at such high cost that much that could have been obtained will never be recovered at all. It can, if it will, compel a cessation of the practice of committing underground waste. It can, if it will, adjust output to market demand and thus let the tankage of excess supplies rest where they should in Nature's costless, wasteless and perfect warehouse. In times both of overproduction and underproduction, it can

secure to lessees generally a realization of a fair ultimate profit on their estates, and to lessors generally a more protracted and satisfying reasonable income, while insuring the public at large a greater certainty of continuity of supply to meet its daily needs over an extended period of time, and thus promote the happiness, comfort and prosperity of the people.

DISCUSSION

Comments at the Tulsa Meeting, October, 1930. *Earl Oliver presiding*

J. A. Veasey,* Tulsa, Okla.—As I view the critical problem of unitization, it amounts to this: It is the contrasting of the natural impulse of man to get as much as he can personally out of a situation—against a situation which demands his yielding to his neighbor, or his neighbors, their own rights in the particular case.

It is absolutely true that the failure of the oil lawyers of the United States to look into the legal aspects of the community ownership of the oil pool has been a pronounced obstacle in the direction of unit development. If his client wishes to proceed independently, the lawyer advises him that he may do so, and it results in such instances as the two attacks we have just had on our Oklahoma conservation law, where two companies having limited acreage in the Oklahoma City pool put their case above the general welfare of that pool; not only the general welfare of other proprietors but their own as well in the long run.

Now I wish to bear on what I conceive to be a merited tribute to some members of my profession. It was my privilege to be in on the conferences leading to the facts of the Champlin case. Two lawyers from the Mid-Continent association were chosen to present the case to the court, Mr. German and Harry Smith; Mr. Ames, of The Texas Co., kindly volunteered his services in the same direction. The members of the Oklahoma Corporation Commission were most intent upon defense of the conservation law and also upon the defense of the order that was under assault. Still another tribute; the Attorney General of the State of Oklahoma lent the full influence and talent of his office, through presenting to us the ablest man in his department, who took a most important part in this case. Therefore, we have a union of public authority and that of the industry itself in its legal aspect, seeking at least to vindicate the economic principle upon which this industry alone can survive permanently.

I would like to make one other addition to the remarks of Mr. German; he rather emphasized the necessity of a statute to compel or at any rate to encourage unit development. Since there has been developed a better understanding of the function of gas in regard to the production of the oil, there is a legal principle as ancient as the law of the Romans that applies and I believe that it is not necessary to invoke statutory regulations necessarily. We can all draw up statutes as desired, but those having contact with state legislatures know that we may prepare a statute wise in its terms and practical also, yet find that the law it produces is entirely different.

I simply mean to say that every point we intended to invoke in the first case brought at Oklahoma City, when the Julian Petroleum Co. violated the proration order, can be invoked through a suit in equity at the instances of other operators of the pool—to bring about the common use of the gas energy, to prevent its waste and improper use, and to require its most efficient use. It is not absolutely necessary to resort to legislative enactments in order to strike down the very thing which has been the chief obstacle in unit development—to teach the producers that each cannot

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do what he wants to do in an oil pool, to the utter disregard of all other operators in the pool. To prevent that condition, according to my understanding, is the ultimate purpose of unit operation and development.

There have been some very serious practical obstacles. Lest I be misunderstood in so stating the situation, I want to say that the organization I represent has been definitely committed to the principle of unit development for years; at any rate, ever since the principle has been in any way generally advocated.

The obstacles I have encountered are as follows—and I think I have said this in practically every meeting in Oklahoma and Kansas to promote this purpose. I have heard views of men on one side or another, I think I have discovered their motives in many instances, when they said that they favored unit operation but their practices did not accord with that statement. One thing that has impressed me is this: The Federal Oil Board, the A.P.I. and practically every one of the major companies, so far as I know, by definite commitments have said they favor unit development. Now either through a loss of contact between offices in New York and offices in Tulsa or elsewhere, the full force of the New York decisions has not been brought home to the local management. So, we find time and again a local manager not very much in favor of this project although his organization at the head is committed. Another thing that we have met with is this: In many of our meetings a proposal has been made that if 18 or 20, or perhaps 30 of the leading oil companies operating in these fields were to commit themselves to the principle that they would not buy acreage unless it were bought under a unit plan—we found that in daily practice these companies were buying acreage contrary to that commitment under certain conditions; perhaps because some other company was buying, or for some special reason of their own, and we sought for days to dispense with such exceptions or agree on them, if exceptions there must be, so that every local manager in these states would know precisely the conditions under which he might buy acreage without insisting on the unitization of that operation.

We found the differences so many that it was impossible for us to lay down or prepare a formula that would become the common project of all those companies. Another factor in the case has been the suspicion of the small operator against the major companies. That is a suspicion that I do not understand, but I fully recognize its existence. That suspicion in one form or another enters into every policy of the industry. The small operator says unit development is a scheme of the majors to put the small fellows out of business. We find this in our practical attempts to unify acreage almost by common consent, and a great deal of argument to support it. The operator owning the larger part of the acreage of the area to be brought under unit development is given the operating control of the property. That has become an accepted principle in this business. So you will find the small operator with but one lease in the area. In some instances the major companies are in control, and the individual ideas of the small operator who perhaps does not participate in the policy under which the property is to be operated—and again the small operator is arrayed against the major companies, whereas the individual profit will be more to the advantage of the small operator than to the major companies.

There is, in this state at least, a vociferous group of men, and I imagine there are similar groups elsewhere—the royalty owners. These exist now more than ever before, and for some reason they are opposed bitterly to the unitization of acreage.

I think most operators will agree that while the consent of the royalty owner to the unitization of the acreage is not entirely necessary, the arrangement works out better in a practical way if the royalty interests may be brought into the arrangement. We sought for weeks here, with an organization representing the royalty owners association, to agree to a form in the lease that would permit that to be done, only to fail completely.

Another thing that was an obstacle for a while, but which is no longer so, was the difficulty we encountered in agreeing on a unitization agreement. It is a complicated legal instrument, and we had as many forms of contract as there were oil lawyers. Then came the question of harmonizing these views, which doubtless delayed the perfecting of the project.

Finally, I return to another situation. I believe that the unit idea eight or nine months ago was definitely in the minds of practically all the major companies in this locality. They intended by every means to further that movement. Then we had to bend our energies to the immediate emergency that confronted us—to the condition of overproduction that was in this state, and the necessity of having meeting after meeting to produce a remedy for the immediate situation. That has certainly more effectively delayed accomplishment in this direction than almost any circumstance I can point to, except that there was a legal doubt as to whether there is an individual right or whether the oil pool was subject to some community character that would give through the courts rights to all the operators instead of to one of them.

It is my position, as pointed out by Mr. Pogue,[1] that we are in a condition of economic maladjustment; not only are we the victims of the general era of overproduction which now plagues practically every basic American enterprise, but we have an added difficulty of our own. That is, an oil producer in our present situation cannot stop drilling, he cannot stop producing, and he cannot limit his production unless his neighbors do the same thing. Our competitive system implies the will and the power in the individual producing unit to adjust his production to demand, whether that be to increase production or retard it. Until we solve that question we are simply an economic anomaly. Eventually we will solve it, and in my opinion the time is not far distant.

W. S. Farish,* Houston, Tex.—It is a pleasure to be here. I feel that I am on the ground floor, so to speak, of the real thought and serious study of the production problems of the petroleum industry. You are dealing with the real necessities of our work.

I think we can all look back over the past year as one of accomplishment in regulating production. I use the word regulating as embracing all types of control and conservation. At the same time we must admit that as an industry we have not made the progress we should have made. I feel that there is no producing organization that is not thoroughly sold today on the fact that to have low costs and best recovery, that is, to have profits from the producing end of the business, it is necessary to remodel our old plan of operation into a new plan which is largely cooperation. In the last analysis it is necessary to have unit operation.

As a matter of fact, the oil industry has never opposed unit operation. As far back as 1901, unit operation has been held out as a goal to strive for. Every operator hoped some time to have an oil field and run it all himself. That would be unit operation. No one ever opposed that idea that I know of—no organization has opposed the principles of unit operation. Proposals to have Congress pass some law that would force unit operation on the industry have met with opposition. The wisdom of such a plan is still a debatable question. So far we have made progress in unit operation only through increased knowledge of the benefit of such operation, and through the cooperation of the state legislatures in California, Texas and Oklahoma.

I think that the industry as a whole believes in the idea that we can lower our costs through unit operation. In fact, we cannot produce our average barrel of oil profitably in the United States in any other way. We must cut our costs. We have had a

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[1] See page 92.

* President, Humble Oil & Refining Co.

decreasing average value of crude over the past four or five years. Our competitors in foreign countries are producing at low costs. Until we reach a stage where we do not overproduce in this country, we will have low-priced crude, and these low prices, with the pressure of competition, will simply drive us to unit operation in order to lower our costs.

Discussion at New York Meeting, 1931. *C. V. Millikan presiding*

J. B. UMPLEBY,* Norman Okla.—There is one question that I want to ask Mr. German but before asking that question I want to define a situation. He said that if engineers could give an estimate of the relative merits of different tracts in a pool, either prior to development or early in the development history of that pool, in the eyes of the court it would only be necessary to show that the estimate was not unreasonable under existing conditions. Is that a correct statement of the proposition?

W. P. Z. GERMAN.—Yes.

J. B. UMPLEBY.—If that is what is wanted of the engineers, the estimate can be largely improved with the drilling of each additional well, so that if the set-up proposed by Mr. German permitted us to drill one well on each 160 acres, say, or some other unit in the pool, from the records of structure of sand conditions, of gas-oil ratios, and of saturation shown by these wells, I believe that engineers would agree in saying that they could give a reasonably close estimate of the relative values of tracts in the pool. They could also tell the approximate size of the pool. The engineer could say that this tract is worth one-fourth as much as that one, or twice as much as some other. I would rather not ask the engineer to go so far as an estimate of barrels recoverable because to do so introduces the variable factors of operating technique and recovery methods. It would seem sufficient to determine *relative* values of acreage to be unitized.

Now, with that statement of the situation, the question I want to ask is how much time Mr. German could allow the engineers for such an estimate, and whether under his plan for exercising the police power of the state by legislative enactment final decision as to distribution of shares of participation could be held in abeyance until some predetermined amount of prospect drilling had been accomplished.

W. P. Z. GERMAN.—That is a very hard question. I have thought about the same thing and have not been able to answer it. This whole proposition is in an embryonic state. What I had hoped to do was to suggest the legal principles and then see whether or not all of us working together could not develop some practical plan. This question raises one of the practical difficulties. We say that when a well is completed it should be allowed to be produced if there is a market for the production. We are thinking of a police regulation designed to enable us to recover the maximum amount of oil at a minimum of cost. To begin with, the very idea of police regulation is to place a restraint on somebody. Now, would it be an unreasonable restraint to say that the first well should not be operated until after we have proceeded with other wells for the purpose of gathering data in order to determine the relative values of the different tracts, and so with the second well, and the third, and so on? Would it be an unreasonable restraint to withhold production until we have obtained this information? The idea of not allowing the well to be produced until some future date is at first view abhorrent, but in the Oklahoma City field all wells have to be shut in for 65 days after they are completed, under the proration scheme, while other wells under the same scheme are allowed to produce. Many of you know how that 65 days shut-in period developed; need I go into it further?

* Geologist and Petroleum Engineer.

If that is permissible, why not go on for six months with the shut-in in order to be able to carry out the plan which we have in mind of setting up a program to enable us to recover the maximum of oil at the minimum cost? That is just a thought. As I said, it is all in its embryonic stage and is subject to consideration.

J. E. Pogue,* New York, N. Y.—Why can you not start a unit operation in a pool of which the limits are utterly unknown? Form an organization or unit corporation, drill the oil and produce it and sell it, and merely defer the subdivision of the profits or the subdivision of the final portion of the profits, or keep adjusting those allotments as the pool becomes outlined. There is no insuperable difficulty in proceeding on that basis.

W. P. Z. German.—The only objection to that program would be, as I understand it, that there might be by the operation of the well, due to its location on the structure, a wastage of gas energy. If it were properly located, I would see no objection to it, but no one knows where it is located until other wells have been drilled and structural conditions have been better obtained.

J. E. Pogue.—Would not the exploratory well for drilling be of as much assistance as the final drilling? There would be some concession on that.

W. P. Z. German.—To operate it to a limited extent, a certain small percentage of its potential, might not interfere in any substantial way, and hence it might not be objectionable, pending the drilling of subsequent wells, to operate each completed well to a limited extent. Mr. Oliver has indicated that such a thing might be done without objection.

J. M. Lovejoy,† New York, N. Y.—The principles applied at Kettleman Hills, of course, could be applied if we had no idea of where the field went, or in which way it extended. The discovery well could be used as a center and a circle with a diameter of two miles, or five miles could be described around it, or a square or an oblong could be drawn, whichever way it was thought the field extended. Then one or two outer circles or squares could be established, controlled perhaps by the market value of leases; and as in the case of Kettleman Hills the participation in the original unit would be on the basis of the most generous probable area, and then have that contracted as it is condemned, but give the man who puts his acreage in the questionable zone a participation in the whole for a certain period of time, whether it is later condemned or not, so as to get him in. So it is perfectly possible to unitize an area even as badly cut up as East Texas. A circle could be drawn around the different wells and unit operation put into effect. Perhaps the inner circle might represent an irreducible minimum of acreage that would command $1000 an acre on the market; that could be put in the first unit and work could proceed from there. The questionable zone might be acreage that would command $500 per acre, etc. There is nothing impossible about getting new areas into units if the desire is there; but I am afraid it is not.

E. Oliver,‡ Ponca City, Okla.—Owners who demand unreasonable terms as the price of their cooperation, in all probability will soon lose this advantage, if Mr. German's theory of the law is correct. It occurs to me that if unrestrained development in East Texas causes oil in that state to go down to 25 and 30¢ per barrel there will be such an overwhelming demand for legislation from operators all over

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* Consulting Engineer.
† President, Mexican Seaboard Oil Co.
‡ Earl Oliver & Co.

the state, and from state officials and other people interested in the welfare of Texas and the conservation of its resources, that some kind of control will be imposed. That demand would be so great that East Texas folks cannot successfully oppose it. In that case the discovery pool could be developed along the line that Dr. Umpleby has suggested, until the edges of the pool, thickness of sand, initial production and other necessary facts are determined, on which we depend for determinations of relative productivity of acreage.

As I understand, it has been the disposition of every court where the question has come up to decide that the state legislature has the authority to regulate the taking of oil from a common pool. Is that correct?

W. P. Z. German.—Yes.

E. Oliver.—No court has decided contrary to that?

W. P. Z. German.—Not so far as I now recall.

E. Oliver.—But the only reason that the practice has not become more general is that the oil industry itself has not asked for that sort of determination?

W. P. Z. German.—Yes.

E. Oliver.—If it were possible for engineers to work out some method of determining relative productivity of acreages in a discovery pool that would appear reasonable to owners and to courts it would be a very simple matter for the lawyers to have that established as a legal principle. I think it is true through all history of the industry that the true measure of equity in public opinion has been that each landowner is entitled to the oil and gas that is in his land; that is, the extractable part of it. There is no sympathy with the idea that if one man has ¼ acre and another has 10 acres, and each drills a well, each is entitled to the same amount of production from the common pool provided their wells have the same initial production. That, however, has been the policy of the courts except when the legislatures have taken a position to the contrary. Public sentiment will support the position that the fellow with the 10 acres is entitled to 40 times as much oil and gas as the man with the ¼ acre.

If the engineers can work up some method, even if it is delayed adjustment, or any other method that looks reasonable, the lawyers will be able to shape up a type of legislation that will simplify the establishment of unit operation very much. The Texas basic law in which ownership in place is recognized is the most favorable of that of any state in the Union to the development of compulsory unitization. Is that not right, Mr. German?

W. P. Z. German.—Yes.

R. Arnold,* Los Angeles, Calif.—In all this agitation for unitization and control of production and general control of the industry, I hope that the lawyers and the legislators and the engineers and the people of the oil industry will not forget the rights of the wildcatter. In 1918, when a number of us were engaged in work with the Treasury Department, one of the questions that came up was a discovery value of land, and those of us who were working in the Treasury tried to arrange so that the benefits out of the discovery value went to the man who made the discovery and not to the people who sat around and risked nothing in the venture.

I have been particularly interested in Kettleman Hills for about 26 years. I was responsible for having about $500,000 spent there in 1910. Our deepest well, 4800 ft. deep, one of the deepest in the world at that time, got within about 1500 ft. of the

* Consulting Geologist and Petroleum Engineer.

producing oil sands. When in the face of the expenditure of $500,000 in this structure people came along and took another chance with $200,000 or $250,000, while others sat around and gave no help whatever—for I understand that not five cents of dry hole money was contributed to the company—and they made the great discovery of the Kettleman Hills, I believe that they should have been given a preferential right in securing the oil and gas from that structure. I raised my voice in protest against the efforts of the entire group of "side-line sitters," the Interior Department and so-called conservationists to curtail the production of the discovery well. That is something that should be brought out in regard to these various fields. The man who risks his time and money and energy and reputation in bringing in fields should be given the edge over those who sit around and watch him do it. Unitization plans should recognize the discoverer of the field. Furthermore, in cases like the Kettleman Hills, the discoverer should at least be given a right to produce his initial well to full capacity even if there is a possibility of a little loss of gas or oil, at least until the stockholders in his company have been reimbursed for the money that they spent in wildcatting in order to find the field.

I happen to know that a good many million dollars were expended by the company that brought in the Kettleman Hills well before it struck the well that was to pay back the money, and just about the time the company thought it was going to have this money come back the Government stepped in and said, "You ought to prorate your holdings with the Standard Oil Co.," and the Standard Oil Co. did not contribute one penny toward that discovery.

My feelings on this question are very strong, and I would like to argue with any of the unitization advocates and lawyers, or anybody else, as to the right of the wildcatters in the laws and regulations that are going to be put into effect from now on. I think they ought to be recognized immediately. Somebody ought to advance this viewpoint before each of the groups that are working out unitization and not leave them out of consideration entirely. We are now establishing the whole basis of unitization, and if we do not at once protect the rights of the wildcatter he will soon be trampled on and will have no incentive to go out and discover pools; the incentive will be absolutely squelched and the wildcatter, like the wild pigeon, will be just a memory.

E. Oliver.—I think we can accept the principle that unitization as a movement, and particularly compulsory unitization, can never become general unless all the equities are recognized. The principle must be absolutely fair and just to all parties, landowners, royalty owners and operators alike. If the discoverer has some equities that merit recognition, some provision must be made for recognizing them. What we are looking for is some practical, sensible and efficient method of developing oil pools. I think the subject brought up by Dr. Arnold is pertinent, but I believe also that it is just one of the details in working out such a method.

F. H. Lahee,* Dallas, Tex.—I fully agree with the opinion expressed by Mr. Arnold and Mr. Oliver, but there is another way of looking at this. I have had enough experience in watching the drilling of wells and also in geology to know that the discovery of a pool is usually a matter of luck. What should we do with the people that drill perhaps 10 or 25 dry holes before they discover a pool as compared with a wildcatter who is fortunate enough to drill his first or second hole as the discovery well of a pool? Is the fellow that drills a great many holes entitled to anything as compared with the discoverer?

R. Arnold.—It was 25 dry holes that finally struck the good one, and they gave him no recognition for what he had spent before.

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* Chief Geologist, Sun Oil Co.

B. E. Lindsly,* Bartlesville, Okla.—Suppose that somebody not here were to drill a well out in New Mexico, or Colorado, or elsewhere, where we do not expect any production, and should bring in 25,000 bbl. and open up a new pool. Just what consideration ought he to have under the present economic conditions?

R. Arnold.—I think he ought to have the right to produee 25,000 bbl. if he can get it into the market. If he drilled in New Mexico, he could not get it out with a freight train.

B. E. Lindsly.—Suppose he could?

R. Arnold.—I think the industry owes him that edge on anybody else, and I think it would be entirely right for the industry all over the country to shut down 25,000 bbl. per day, prorate it around, in order to give him a chance to receive the benefit from his nerve and energy in discovering a new field.

J. M. Lovejoy.—I must respond to Mr. Arnold. I went to California last summer to join in the negotiations for the Kettleman Hills unit plan for the company that discovered the field, and I made a great effort along the lines of Mr. Arnold's suggestion, that the discovering company should be given a preferential right. I was told, rather to my surprise at first, that instead of a preferential right the company ought to be penalized; in fact, the head of one of the largest companies rather lost his temper one day and said, "Why, you wildcatters are enemies to the oil industry." At any rate for the present, and until our huge potentials have been somewhat depleted, I do not believe the wildcatter can expect to receive preferential consideration from the industry. If there were a scarcity of oil, yes; but not under present conditions. Anyone who undertakes wildcatting now does so with full risk and knowledge of the economic situation and cannot expect too much consideration from anyone.

In the case of a unit operation he should be given, and in most cases, I think, he is given, the right to produce his well for a certain time unrestricted, to get his money back and a premium; in fact, most of the projects that I know of have allowed for that.

I want to add one other remark about unit operation in general. If legislation is to be drawn up with regard to unit operation, you gentlemen will probably have something to do with it. From the experience that I had in the Kettleman Hills unit negotiations, I would suggest that no attempt be made to weight the value of the different parcels of land. We got into that in Kettleman Hills and found it impossible. We tried to weight parcels with respect to their position on the structure, but the value of the top acreage on the structure with high gas-oil ratio was offset by the owners of flank parcels, but the flank people with the sound argument that the flank was the place that would produce the most of the oil. Finally, we abandoned the attempt and put every acre in equal, and I think that is the simplest, easiest and most logical way to do it in any field.

In Kettleman Hills we have a system for throwing out commercially nonproductive acreage; that is, to take care of edge acreage. The man who has his property on the edge of the field produces it first, and ultimately the wells become commercially nonproductive, he is given a credit of 50 per cent. for one or two years after his lease becomes nonprofitable, and then his lease is thrown out.

V. R. Garfias,† New York, N. Y.—Some of the troubles that Mr. Arnold raised come from his trying to apply this law retroactively. He drilled his well before there was any talk about unit operation. The man who starts wildcatting now knows about unit operation; he is forewarned about it, and if he does not want to take his chance, then let him drop it.

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* Senior Petroleum Engineer, U. S. Bureau of Mines.

† Manager, Foreign Oil Dept., Henry L. Doherty & Co.

F. G. Clapp,* New York, N. Y.—It might be interesting in the same connection to know the New Zealand experience. We wrote what was called a community lease, by virtue of which the man whose land was drilled was to have a certain royalty interest in the oil, and all other lessors were to have a percentage of the balance of the royalty.

W. P. Z. German.—In my paper I had not forgotten the pioneer's rights. That raises a serious question, and it should not be overlooked. However, it occurred to me that possibly it did not raise a question that would ever give us any trouble, because if we know that every pool that is brought in is going to be unitized because required by statute (this, of course, assumes that we are going to have a law that would require unitization), if one knows that when he gets a well the pool is going to be unitized, he will in all probability, by agreement with several other leaseholders, unitize a lot of the area, and they will share with him the risk of the dry hole. If they get production, there is a considerable group that is in the position of the pioneer, and they would be willing to go along without claiming any special benefits by reason of it.

E. A. Stephenson,† Rolla, Mo.—That is what I had in mind for any particular pool. The pressure within the pool is usually almost uniform; theoretically it should be uniform. Where development is most concentrated removal of the oil and gas lowers the pressure in that vicinity so that a differential pressure exists between that point and the rest of the pool, hence flow towards that point is greatly accentuated, although the shape of the reservoir, the steepness of the dips and the methods of operating also affect the rate of flow. Under unit operation, properly controlled, development of the pool proceeds in an orderly manner and the decline in pressure throughout the field becomes more nearly uniform. That is an ideal which we would like to approach.

M. Lee,‡ Wichita, Kans.—In these trying times everyone is attempting to do what he can to smooth out the difficulties of proration. One thing that is overlooked is the refinery relationship and the factor that it is in buying the crude. In an instance or two that I know of a refinery might have a contract for one source of supply. When that supply is prorated below its market demand, this refinery cannot supply customers it has had for years. We have never prorated any other refinery nor made any movement to divert gasoline to that company's market. Therefore, it must be cut off permanently probably from the market that means the existence of the company. If we will take into consideration that fact in proration I think that many of the peopie that are trying to practice it will no longer do so and we will achieve something in sound economics instead of confining our attention to crude proration, through which one's source of supply may be taken away from him.

V. C. Smith,§ Charleston, W. Va.—In setting up gas-oil ratios, it is sometimes overlooked that the value of the gas under certain circumstances exceeds the value of the oil. Sometimes the gas is worth 45¢ per thousand, and when the cost of production is considered, it is more profitable to the operator to produce and sell the gas. We are valuing on an energy basis entirely. We ought to value on a chemical basis. A few years ago we were producing gas solely for energy. The utilization of natural gas as a source of raw products for the chemical industry, as, for instance, the making of alcohol and other products, has changed the picture rapidly. The same thing is true to a smaller extent with crude oil and new markets are constantly being opened. Gas in some cities is being sold on a B.t.u. basis. The next step will be its valuation on a chemical basis.

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† Professor of Petroleum Engineering, School of Mines and Metallurgy, University of Missouri.

‡ Consulting Petroleum Geologist.

§ Consulting Geologist.

H. J. Wasson,* New York, N. Y.—We have heard about the various production variables—chemicals, energy, different gas spots in the field, etc. One individual has a lease that is rich in oil, another one rich in gas, and perhaps there are three or four other variables mixed up in the situation. In my judgment, we are being too precipitate about throwing these matters to the legislatures of our various states and asking them to draft legislation to control the working out of problems of this nature. We recognize that unit operation is the most efficient. That, I think, is evident; but all the notable examples of unit operation that have taken place since the subject first became a live topic have been worked out through private initiative, possibly with the exception of Kettleman Hills. It may be that there the Government brought it about, but I doubt it, because even in Kettleman Hills one or two held out. So even there it is not a clear case of legislative compulsion dictated by government. It was dictated by economic common sense. The same is true with respect to the Van field, and the same with all unit operations in foreign countries. I apprehend very seriously that we are making a mistake in establishing legal regulations for this involved question at this stage of our knowledge. A unit development should be the resultant of a great many economic forces together with private expediency and the profit-earning features. The only reason for having it in the first place, I suppose, is to increase the profits of the people who join in unit operation, because if that is not the reason, why have it? If that is true, it is simply logical to suppose that it will come about rationally of its own accord when it is generally known that it is the thing to do.

V. R. Garfias.—For the last 10 years we have been hearing about unit operation and waiting for all these natural laws to develop by themselves without any legislation. The oil business is really in a serious situation, and all these individual efforts or talk for 10 years have really accomplished very little. Some legislation that will make unit operation legally feasible is essential.

H. J. Wasson.—I did not make my remarks as drastic as I really felt. First, as I explained, I believe in unit operation. If I had an oil property subject to uneconomic drainage I would endeavor to get the surrounding neighbors to join in on some unit scheme, and whether we drew an oblong, or circle, or what not, I would be in favor of it. However, I am strongly against the compulsion idea which is advocated very insistently in some quarters. Mr. Garfias says that the oil industry is in a serious situation, and I agree; and, of course, we all agree. So is the wheat industry. So is the cotton industry. So is the copper industry. So is the coal industry. And for that matter every industry is more or less in difficulty at this time. However, the tendency now when an industry gets into difficulty is to dash to the state legislature or to Washington and form a board, or pass a law designed to increase its profits or save it from further difficulties. Then when we examine all the results of the various things done along that line, what do we find? The Farm Board, for instance, has spent a billion of the taxpayers' money and has for its showing merely the proof that even the Government can lose money in commodity speculation as fast as any of us can in the stock market.

I have been waiting to hear during this meeting someone propose an oil board. As long as we are talking about government help, I see no reason why we should not carry that thought to its logical conclusion and do as the farmers did—have an oil board. What's another half-billion to the public treasury? Think of the distress oil it would take off the market! I question governmental help or legislative help now. Eventually, I can visualize a condition when we must perhaps have government control of everything we do, but, as I have said at many former meetings, we have already an excessive amount of government interference with business, and I am still strongly opposed to increasing the burden.

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* Consulting Engineer.

Cooperation between Engineers and Lawyers

By Peter Q. Nyce,* Washington, D. C.

(New York Meeting, February, 1931)

Law is as old as civilization. In its early stages the so-called law of the jungle, "the survival of the fittest," was entirely operative. Man was quite largely a law unto himself and was likewise his own lawyer. As civilization developed and individuals segregated themselves into bands or communities, man-made laws became a reality, the individual sacrificing certain privileges for the benefit of the band or community in which he was privileged to live. Our present system of law is a continued development of that process. Very early in this development the exigencies of the occasion called into being classes of individuals who were given to study the laws then existing, and this group became known as lawyers. They advised what could or could not be done under existing laws. They were the aggressors in formulating new laws and principles under which the communities must live.

Concurrently with the development of the law and the lawyer, the engineering profession was born. In our early civilization, each man was his own engineer; he built his own home, constructed his own bridge, and provided his own means of conveyance. As civilization became more complex, technical study was required to consummate projects and thus meet the requirements of an expanding community. The engineering profession assumed this burden.

Both groups were human and thus susceptible to human mistakes and errors. It was Macaulay who said: "The world generally gives its admiration not to the man who does what nobody else ever attempts to do, but to the man who does best what multitudes do well."

Birth of Petroleum Industry

In 1859, by the completion of the Drake well in Pennsylvania, the petroleum industry as we know it was born. Its rapid progress since that time has been both extraordinary and remarkable.

The zeal of the individual operator to secure all possible oil in the shortest time, even to the extent of bringing into possession a part of the oil underlying a neighbor's property, developed unnecessary drilling, wasteful methods of recovery, great loss of gas, the early abandonment of property with much unrecovered oil thereunder. Such methods, plus

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the efficient and expert advice of the petroleum engineer and geologist in recommending to the operator where to drill or not to drill, have led in recent years to gross overproduction, a problem which the industry itself has not yet been able to solve. If we were presently pursuing the course of the now archaic oil and gas operator who did not follow scientific advice, many pools developed during the past decade would still be undiscovered.

Conservation, Unit Operation and Cooperative Development

Wasteful methods and overproduction have now forced upon the industry conservation, unit operation and cooperative development. These principles embrace the panacea for the industry's solution of its present problem. This program is necessarily difficult of accomplishment because of present existing laws, both state and federal, novel engineering principles involved and selfishness which competition necessarily fosters. Conservation, in the sense in which I now use it, unit operation and cooperative development were abhorred generally by the industry in the not far distant past.

They afford a solution for the present overproduction, which has resulted largely from the early laws and court decisions holding that he who first reduced oil to possession became its absolute owner. The petroleum engineer has evolved principles which make possible orderly drilling, the production of oil as the market demands, protecting the property rights of all and with injury to none. Subsequent laws and court decisions are adjusting themselves to such a course. These novel ideas, so far as I know or have been able to learn, were expounded first by petroleum engineers. This program when first advanced was considered impractical, ill-advised and was not accepted by the industry. It was considered a reform, and most reforms which we have tried in recent years have proved unsuccessful.

Man-made laws will not successfully supplant natural laws, but man-made laws should and ultimately must harmonize with such laws so that the latter may properly function. Consequently, conservation, unit operation and cooperative development have thus thrust themselves upon the oil and gas industry.

Further Education Needed

This has been accomplished largely through education. Universal acceptance and successful operation of these principles depend upon the further education not only of the oil and gas producers but of our legislators and the public as well. The promotion of such education must necessarily fall largely upon the executive, the petroleum engineer and the lawyer. So far as the engineer and lawyer are concerned, this service must be performed largely without compensation. Our late

President Roosevelt has well said that: "Every man owes some of his time to the upbuilding of the industry or profession to which he belongs."

From the lawyer's standpoint, this problem has been a blessing in one respect at least, if not more. It has established a close contact between the engineer and the lawyer. The lawyer has been honored with the privilege of working with other professions. In our practice we work with the doctor, accountant, and in this recent development, the engineer. I have never believed in the dual purpose lawyer. It is well for the lawyer to understand some of the principles of medicine, accounting and engineering—such an understanding greatly helps him in his profession—but I am opposed to the lawyer who would endeavor to practice medicine, accounting or engineering. The attorney should confine his activities to his own business, have general information of other professions but obtain his technical information and advice from the particular specialist involved. There is and should be no occasion for jealousy between our professions. Our primary object must be the solution of the problem jointly given us to solve. There is glory enough for all when the solution is achieved. I have observed jealousies in my own profession. As much can doubtless be said of yours. How can the engineer and the lawyer best cooperate in solving these problems? I shall not discuss the laws and decisions with which the lawyer and engineer must cope in this matter, because that subject has been discussed in another paper.[1]

The President of the United States has taken cognizance of the seriousness of our oil situation, and in 1924 created the Federal Oil Conservation Board, composed of the Secretaries of Interior, War, Navy and Commerce. This Board, while without legal power, has conducted hearings, has received reports from engineers and lawyers and has made reports to the public. These reports have been a real instrumentality in the campaign of education.

The American Bar Association has given serious consideration to oil and gas law. The Mineral Section of the Association was created in 1926 as a result of a rather general demand on the Association, that a study of mining and mineral laws be made.

The Secretary of the Interior in 1927, in an address to the Mineral Section, requested that Section to appoint from its membership a Conservation Committee of Nine to help solve the problem of waste and overproduction. A Committee of Nine was appointed by the Chairman of the Mineral Section for such a study. The Secretary of the Interior chose three members from that Committee in constituting a Committee of Nine to study the question and recommend legislation if the latter were desirable.

The Secretary's Committee of Nine was composed of three members of the Mineral Section Committee, three members representing the

[1] W. P. Z. German. See page 11.

United States and three members selected from the American Petroleum Institute. This Committee had as its technical advisers petroleum engineers selected from the Departments of Interior, Navy and Commerce. A report was made to the Federal Oil Conservation Board.

The Mineral Section Committee of Nine has continued to function since 1927. Its scope has been extended by the appointment of subcommittees in most of the oil-producing states and these subcommittees are studying local situations within the states. The Committee of Nine and the subcommittees will respond to the invitation of any public official or responsible group desiring professional advice involving the subject matter under consideration. This Committee has recently worked with at least one Executive Department, advising the form and contents of federal legislation. In giving such assistance, the Committee cooperated with the petroleum engineers whose advice they sought in arriving at what appeared to be sane and sound conclusions.

The joint services of the engineer and the lawyer must necessarily be required in solving such problems. The petroleum engineers and lawyers must become better acquainted with the subject matter about which each must know. The engineer must learn that political laws are changeable and that the construction of such laws by courts change with changing conditions. The lawyer must learn that physical and economic laws are not changeable. The Mineral Section of the American Bar Association has been addressed by engineers at some of its meetings. The appearance of lawyers before your body convinces me that you are following the same course. We are educating each other by such appearances. The result must necessarily be most wholesome in helping to solve our joint problem.

Government Approval

The Congress last July passed an Act permitting unit operation and cooperative development on public lands (Public No. 527, Seventy-first Congress). That Act expired by limitation Jan. 31, 1931, and there is presently before Congress a bill continuing the life of such Act (S. 6128). Under the Act, the Kettleman Hills unit operation project has been consummated. This action definitely places the stamp of approval of the Government on unit operation and cooperative development.

After the determination to work out a unit plan in Kettleman Hills had been reached, a Committee of Engineers was appointed by the parties interested to work up engineering data. A Committee of Lawyers was likewise selected. After all the ideas had been completely worked out between the engineers' and the lawyers' committees and accepted by a general Committee of Operators, a special committee of lawyers was selected to work out the final draft of what is now known as the Kettleman Oil Association agreement. This agreement when in final form was

approved by the General Committee of Operators and the Department of the Interior.

Unit operation and cooperative development on privately owned lands present certain difficulties. Efforts have been and are now being made to secure proper state legislation in several of the oil-producing states. The Sherman Antitrust law and the Clayton Act present additional obstacles where Interstate Commerce is involved. On Dec. 17, 1930, Representative Graham presented a resolution (H. Res. 322, 71st Congress, Third Session) in the House of Representatives, as follows:

> Resolved, That the House Committee on the Judiciary, or any duly appointed subcommittee thereof, be, and is hereby, authorized to conduct an inquiry into the power of the Congress of the United States to establish an administrative tribunal, with authority to render advisory opinions as to whether or not submitted commercial contracts or agreements affecting interstate commerce are or are not violative of the Antitrust Act, and the advisability of the adoption of such a policy; and for the purpose of this resolution the committee or any subcommittee is authorized to hold hearings and receive testimony, to sit at such times as may be necessary, whether or not the House be in session, and that at the conclusion of such hearings the committee shall report its findings to the House of Representatives, together with such recommendations for legislation as it may deem necessary to propose.

It has been apparent to those who have given consideration to the matter that the present federal antitrust laws have been harmful in certain instances to the proper functioning of business. From those laws, by the subsequent enactment of Congress, mergers of railroads approved by the Interstate Commerce Commission have been excepted. Another exception to the operation of those laws exists in the cooperative marketing of agricultural products. Likewise, there is excepted persons or corporations engaged in export trade.

I hope that the Graham or some other proper resolution is passed authorizing an investigation to determine whether agreements affecting irreplaceable natural resources should be expected from this Act or approved under some amendment thereof. Such a study would be wholesome and should receive the support of your body. In the event such a study is authorized, the burden of convincing Congress of the merit of this proposal so far as oil is concerned, must rest upon the petroleum engineer and the lawyer.

Laws Should Change to Accord with Economic Conditions

Many laws which are entirely proper when passed, become obsolete and unworkable with the changing economic conditions.

Dean Young B. Smith of the Columbia Law School, calls attention to "intellectual inbreeding" in the legal profession. This, he says, is due to the lack of the proper and dynamic touch with life and society. He asserts that seldom do the courts utilize the knowledge of the econ-

omist, the historian, the psychologist or the philosopher in determining social policy. As a result, legal standards are often inconsistent with actual experience.

In recognition of this situation, George Washington University has instituted a combined course in engineering and law. President Marvin in a communication to the author, said in part substantially as follows:

> Not only on account of the increasing complexity of the economic society in which we live, but because of the rapidity with which intricate decisions must be made and because there has been a breakdown in the miscellaneous assortments of apprenticeships, the universities have been increasingly called upon to develop men technically trained in one or more fields and able to correlate the work they have in hand in an understanding and purposeful way with another or other equally technical and highly professionalized service or services. Emphasis in all organization of study is being placed upon the social economic point of view. It is necessary for a man to be able to orient his work with the social, economic, and political tendencies about him, if he is going to be an effective servant in the community in which he lives. This is especially true if his profession be that of the law or of engineering . . .
>
> Herein we find an immediate relationship between engineering, especially mining engineering, and the law. It would not be too much to say that in the cases of many executives it is the law plus that makes him successful, and the plus represents important administrative or engineering training or both.

The laws of nature are unchanging and unchangeable; they are inexorable. The engineer strives to solve them, to explain them, to formulate them. The lawyer then must apply them to human relationships so that they shall become of practical value and use to mankind. It is, therefore, the function of the engineer to outline the conditions under which oil fields should be developed and of the lawyer to determine the method by which that can be legally accomplished.

Unit Operation in Foreign Fields

By E. L. Estabrook,* New York, N. Y.

(New York Meeting, February, 1931)

Oil companies operating in foreign countries have made increased use during 1930 of cooperative agreements in prospecting unproven territory and in developing proven territory. A considerable proportion of the existing foreign fields are held under single ownership and have been developed as units. The operating companies seek to maintain this condition by acquiring land in large blocks or by merging smaller concessions under unit operating agreements.

Your committee has secured a number of reports on foreign noncompetitive operations and a valuable formal paper which deals with the Golden Lane of Mexico.[1] O. B. Knight has drawn some valuable comparisons concerning costs of development and ultimate production between a certain competitive area and another noncompetitive area along that strip of rich producing territory. After discussing details of production, numbers of wells and cost of drilling and production, he concludes that the 93,700,000 bbl. of competitive oil will have cost $0.193 per barrel as compared to 85,700,000 bbl. of noncompetitive oil at $0.059 per barrel. The saving of $0.134 per barrel amounts in round figures to $11,500,000, which is 2½ times the total cost of developing the noncompetitive block. The cost for drilling and development of the two areas of 3550 acres which Mr. Knight compares was $18,150,000 under competitive and $4,760,000 under noncompetitive conditions. The estimated ultimate production of the competitive 3550 acres is expected to reach 93,700,000 bbl., or 8,000,000 bbl. above the noncompetitive block. Under ordinary production methods it is to be expected that a noncompetitive area will yield less oil per unit area than will a similar competitive area, because of closer spacing and more rapid extraction in the latter case. The advantage of noncompetitive conditions, in this regard, is that the undivided ownership makes it possible to apply repressuring as a production method fairly early in the life of the field and thus, in the end, to vastly increase the yield. In the particular region described by Mr. Knight, repressuring is not thought to be a factor of

* Petroleum Engineer, Pan American Petroleum & Transport Co. Chairman, A. I. M. E. Committee on Unit Operation in Foreign Fields.

[1] See page 98.

importance, because the bulk of the oil is found in supercapillary openings, and a high percentage of recovery is obtained during the flowing stage of production.

We are indebted to Mr. Charles Bohdanowicz of Warsaw for the following notes on oil field development and operation in Poland.

"In the course of the last two years (1929 and 1930) an almost negligible number (30) of explorative wells has been drilled. Of that number only a few might have been located differently had cooperation existed between the firms engaged.

"Absence of competition in wildcatting is a consequence on the one hand of the lack of suitable new tracts having commercial possibilities, and on the other hand it has its source in the character of the capital engaged in the Polish oil industry, which is disinclined to take risks. Some influence toward elimination of competition along those lines must be ascribed to the cooperation of the Government with the large oil concerns of the Pioneer Co., Ltd., having for its purpose exploration and wildcatting at joint expense and under one management.

"In Poland, the law of 1908 provides for spacing wells, exploiting one and the same horizon at 60 m. (197 ft.) as minimum. The project of the new mining law provides that spacing of wells is to be determined for each field by an authorized commission of geologists and engineers.

"The largest Polish pool, that of Boryslaw, giving about 70 per cent. of the total Polish production, has approximately 2000 wells. By spacing wells more sparsely in some portions of those fields, it would have been possible, had the large and small concerns working there cooperated, to dispense with about 20 per cent. of the wells actually drilled, saving thus approximately $60,000,000.

"Cooperation was introduced lately in the southern portion of the Boryslaw area, which has permitted wells to be spaced more rationally. In the remaining smaller fields, in the eastern and western portions of the petroliferous province, the loss through improper spacing is not so large for the reason that fields there had been spaced on the whole more adequately.

"Air-lift and gas-lift and repressuring methods are still in the experimental stage in this country, and for that reason no adequate data are available. Adoption of cooperative exploitation is rendered difficult by excessive subdivision of oil tracts owned by many small operators."

One sees little in the public press concerning operations in the thoroughly unitized foreign fields, but consistent progress in technical advancement is being made in most of them in spite of the depression in petroleum prices. Natural-gasoline plants are being installed or increased, repressuring on a more or less experimental scale is being carried on in many of them, and almost everywhere deep holes are being drilled in an attempt to obtain a better idea of the extent of oil reserves,

in order that physical installations may be of a type and character more commensurate with the length of service required than were those more or less temporary facilities with which the first development was carried on. Without the stimulus of competition, progress is often slow, but fortunately the petroleum industry is feeling the vivifying effects of the influx of young engineers who have been entering the business in increasing numbers during the past 10 years. The importance of natural gas in oil production is being more widely recognized, and plans for conserving it and for utilizing its energy content are being advanced in every oil field. Vast amounts of gas are still escaping into the air because no use can be found for it, and this loss must be a consistent challenge to the industrial chemists and fuel-distributing companies.

Were the oil industry not afflicted with so many weaknesses, one might be tempted to suggest that its greatest handicap in the United States is the divided ownership of the subsoil, which puts the selfish interest of a vast body of land and royalty holders on the side of rapid exploitation for immediate profit, rather than on the side of conservation and sane extraction. Too much competition in the production of oil results in losses to society that are beyond calculation from its waste of human effort, unnecessary capital expenditure and dissipated physical resources.

Control of California Oil Curtailment

By Robert E. Allen,* Los Angeles, Calif.

(Los Angeles Meeting, October, 1930)

The organized curtailment of California oil production is not yet one year old but during its first year it has accomplished so much that it is now firmly established as an agency of economic efficiency. The principle of cooperative curtailment has been adopted by other states and it is safe to say that the principle will continue as long as the demand for petroleum is notably less than the potential production. It is interesting to note that this same principle of regulating supply to meet demand is now being urged for other industries, such as agriculture and mining.

Since Oct. 31, 1929, when curtailment was instituted by the oil producers of Santa Fe Springs and Long Beach in an effort to avert the disaster of ruinously low prices which confronted them, there has been a constant and increasingly effective curtailment program in California. Prior to that time a notable effort toward the restriction of oil production was made under the direction of F. C. Van Deinse during the early summer months of 1929. A considerable reduction of oil output was recorded as the result of this effort, but because of incomplete cooperation and the discovery of still deeper zones at Santa Fe Springs the effort was abandoned; flush field production became unrestrained and prices soon fell to low levels.

This initial curtailment movement was educational and experimental. It showed all operators a way out of their overproduction difficulties and developed the principles followed in later curtailment efforts. Thus it was that only a few days after their oil had been reduced to 60 c. per barrel, the operators of Santa Fe Springs got together and agreed to restrict their current production of more than 270,000 bbl. daily to not more than 150,000 bbl. daily. The operators at Long Beach followed the same course a few days later and agreed to limit their production to not more than 110,000 bbl. daily.

The Santa Fe Springs operators chose H. P. Grimm as umpire and director of their proration program. Neal H. Anderson was chosen umpire for Long Beach. Since that time, as the need for curtailment has increased, practically every field of the state has come under the curtailment of these two umpires. Curtailment of the Elwood and

* Assistant Umpire, California.

Ventura Avenue production became necessary in December, 1929, and in February, 1930, a General Committee was established to direct the application of curtailment to every important field of the state.

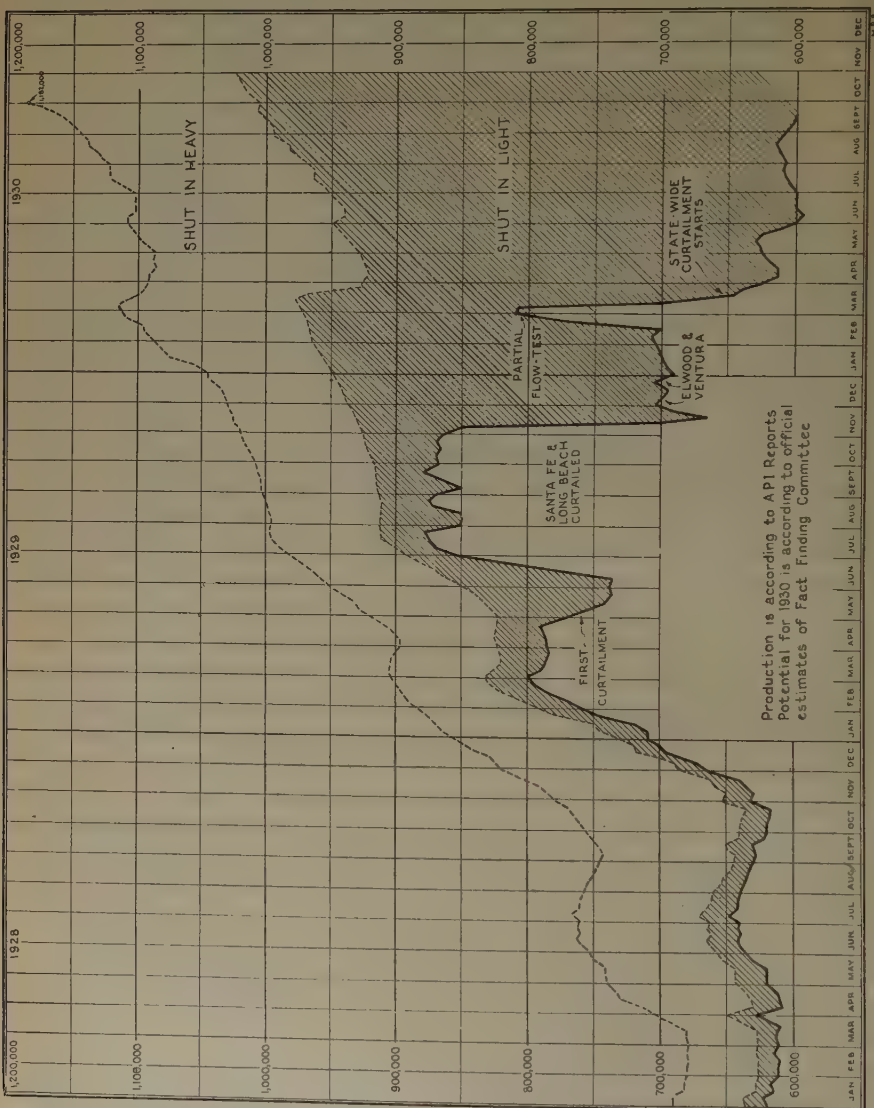

FIG. 1.—PRODUCTION AND CURTAILMENT IN CALIFORNIA.

A five-day flow test to determine the actual potential production of several important fields was conducted during the third week of February. As a result of this flow test, during which state production jumped to 806,000 bbl. daily, an Engineering Advisory Committee determined the true potential of the state to be 1,095,000 bbl. daily.

California had been allotted a production of 610,000 bbl. daily by President Hoover's Committee on Petroleum Economics for the survey of the oil industry's requirements for 1930. The California General Committee set the allowable production of the state at 609,000 bbl. daily and directed all field committees and the umpires to prorate their production on that basis, effective March 1, 1930.

Under this program, the production of the state showed a notable decrease. February production averaged 745,916 bbl. daily; March, 635,483 bbl. daily; April, 625,625 bbl. daily and May, 614,337 bbl. daily. Only for a few days did production drop to the required 609,000 bbl. daily. This failure to reach the objective, together with a steadily increasing state potential and a slight recession in demand, forced the General Committee to lower the state's oil quota to 596,000 bbl. daily, which was a compromise figure between the previous daily quota of 609,000 bbl. and a recommended quota of 575,000 bbl. daily.

The new quota of 596,000 bbl. daily became effective May 16 and, like the previous quota, became a goal to strive for rather than to attain. On only a few days between May 15 and September 1 did California production fall below 597,000 bbl. daily. A steadily increasing potential and the development of the Playa del Rey field, together with numerous big wells at Long Beach and Elwood, combined to keep the state's production above the mark set for it.

The results obtained to date from the curtailment of California oil production may be seen by reference to Fig. 1, which is self-explanatory. It is difficult, of course, to place an actual cash value on any project as conditional as curtailment, but Herbert R. MacMillan, president of the California Oil and Gas Assn., has stated that oil producers of California benefited to the extent of at least $88,000,000 by statewide curtailment during the first six months of 1930.

Application of Proration

Soon after the beginning of cooperative curtailment in California, it became apparent that if proration was to be uniform and consistent in its application it would have to be accomplished by certain definite rules. As there were no rules in existence at that time governing oil proration as practiced in California, it became necessary to assemble certain provisions of various curtailment agreements, together with important rulings of the General Committee, the Field Committees and the Umpires. This was done and a set of rules or code of procedure was thus established, which, with occasional amendments, has governed the application of curtailment in California. Some of the more important paragraphs of this code will be quoted hereafter. For instance, the purpose and basis of proration are defined as follows:

A.-1. *Purpose of Proration.*—The regulation of crude oil supply to normal demand shall be accomplished by equitably distributing among contributory fields and operators the total production required. This division of market outlet is commonly called proration of production.

A.-2. *Basis of Proration.*—Proration shall be based proportionately upon the actual or estimated potential production of any well, lease or field for any given period of time.

Inasmuch as California proration is based upon the potential production of wells, leases and fields, the following paragraphs from the code may be of interest:

B.-1. *Definition of Potential.*—The potential production of any well or lease is the average amount of oil the property is capable of normally producing under conditions prevailing at the specified time.

B.-2. *Actual Potential.*—The actual potential of a well shall be ordinarily established by taking the average of the last four of first five full days of normal production after completion or during any subsequent flow test. Certain modifications may be made in the application of this rule when conditions require.

B.-3. *Estimated Potential.*—The estimated potential of any well or lease shall be determined by projecting the normal past performance of the well or lease. Consideration must be given to any actual or anticipated change in the conditions affecting the producing unit.

B.-4. *Units of Potential.*—In the estimation of potentials all large and recently completed wells shall be considered individually, but all settled production may ordinarily be estimated by leases.

It is evident that the accurate determination or estimation of potentials is one of the most important elements of proration. Open-flow tests of entire fields are frowned upon by the General Committee as being generally unfeasible on account of the large amount of surplus oil that results. It is entirely possible for a new well to establish its initial potential and then be prorated entirely upon the basis of its estimated potential until it goes on the pump or the gas-lift, hence it is necessary that the greatest accuracy and the best judgment be exercised in the estimation of potentials. An explanation of the methods used in estimating potentials will be given later.

Various fields and groups of fields have been assigned differing amounts of allowable production by the General Committee. Thus group 1 comprises the nine flush fields of the state, which are not regarded as a menace. Ordinarily the total potential of this group averages about 660,000 bbl. daily, but since July 1 it has been steadily increasing until it is now well over 700,000 bbl. daily. Regardless of the potential of group 1, its allowable production cannot exceed 355,000 bbl. daily, under the rule adopted May 15, 1930 and still in effect on Sept. 10, 1930. The distribution of this allowable will be explained in a subsequent

paragraph. In group 3 are the so-called menace fields of Kettleman Hills and Playa del Rey, which are given special attention by the General Committee. In group 2 are the other 30 fields of the state, with variable allowables based upon conditions prevailing in each field.

About the middle and near the end of each month the umpires submit to the Advisory Committee a statement of the estimated potential of each field for the ensuing half month. After these potentials are approved, the allotment of each field is prorated among the various producers in that field in direct proportion to their respective potentials. Thus the percentage curtailment required may vary from 10 to 70 per cent. between different fields but within a given field all operators are expected to take the same amount of curtailment except in a few special cases.

After the allotted production of any given lease is determined, such allotment is credited with previous underproduction or debited with previous overproduction. This corrected allotment becomes the allowable production of the lease for the period and is the figure with which actual production is compared in determining overproduction or underproduction, and it is also the amount of oil that is certified to the pipe line company as being eligible for purchase. The following rules relating to allotments and allowable production are given:

D.-1. *Basis of Allotment.*—The lease shall be the effective unit of proration and production allotment. The community lease or a group of pooled leases under one ownership or management may be considered as one lease if the interests of adjacent operators are not thereby prejudiced.

D.-2. *The Allotment.*—The production allotment for any lease shall be that assigned portion or percentage of the potential production, which the lease may ratably produce. The allotment is determined by multiplying the potential by the applicable percentage.

E.-1. *Definition of Allowable.*—The allowable production of any lease for any period shall be the allotment for the period adjusted for prior excesses or shortages.

Naturally, any system of proration requires constant control if it is to last. The first measure of control is the determination of the performance of individual producers. Oil produced and sold or held for sale is determined from monthly statements of pipe line runs and field stocks. These are furnished by the purchasing companies as well as the producer and furnish an absolute statement of marketable production, which is the basis of judging an operator's curtailment.

However, these monthly statements are too infrequent and too long delayed to furnish prompt information regarding the production of various fields. It is necessary, therefore, to require daily production reports from each operator in all the important fields of the state. In this manner a very close daily estimate of the state's production is

obtained. It is this daily figure that enables the industry and the public to know the day-by-day status of the curtailment program, and also permits the immediate exposure and prompt remedy of infractions.

Preliminary statements of an operator's monthly production are made on the basis of the daily production reports, but these statements are always corrected by comparison with the oil inventories as shown by shipments and stocks.

Limitations of Potentials

Because of the constantly mounting potential of the state, due to the development of new fields and the revival of old fields, and also to the surprisingly slow decline in potential of severely curtailed fields, it became necessary on August 1 for the General Committee to reaffirm and insist on the enforcement of a theretofore unapplied ruling which had been made as of May 15.

The intention of the rule was to discourage drilling and the development of new production. Simply expressed, this rule prohibits new wells from participating in the effective potential and in the allotted production of the state until old wells have declined an equivalent amount. In practice, the effective potential and allotment of every lease and field in the state is fixed at an amount that is subject to decline as it occurs, but which is eligible to increase after the development of a greater actual potential only by pro rata participation in the decline of other units.

This rule has been effective since August 1 and has been only partly successful. In some fields it has been very effective and in others it has been rather difficult of enforcement. An illustration of its application may be seen in the Elwood field, which had a potential of 79,380 bbl. daily and an allotment of 41,355 bbl. daily for the August 1 to 15 period. For the August 16 to 31 period, the actual potential had increased to 104,160 bbl. daily, but the effective potential had increased only by a 995-bbl. daily share of other fields' decline. The effective potential was only 80,375 bbl. daily and the allotment was 41,955 bbl. daily. Thus the bringing in of 24,780 bbl. daily of new potential added only 600 bbl. daily to the allotment of the field, and there would have been no increase in the allotment had it not been for a decline in other fields of group 1.

Obviously enough, the strict enforcement of this rule will tend to maintain the status quo of fields and will strongly discourage the development of new fields that can obtain a place in the group only by the decline of old fields. Within fields a certain flexibility of application has been provided so that wells on new leases are not unduly penalized.

This rule has been both praised and condemned according to the viewpoint of the observer. While it represents an important innovation

in control, it is certainly one of the logical steps which the oil industry must take as it advances toward the goal of stabilization and self-control. It tends to discourage unnecessary expenditures for drilling wells that cannot be produced until the oil is needed, and at the same time protects the declining field from being further curtailed to make room for new flush production. The operator who does not drill is thus protected against the excessive drilling of the one who does.

Engineering Control of Proration

The original establishment and the frequent revisions of potentials for practically every well and lease in the State of California was a task of such magnitude that mass-production methods had to be adapted to the accepted technical practice of estimating potentials. It became necessary to estimate future potentials of a well or lease with unbiased accuracy, for the amount of an operator's income depends on the potential assigned him.

As previously indicated, the initial flow test of a well is often the only fact that can be definitely established during the entire flowing life of a well under curtailment. There is no period of normal decline and there is no normal decline in near-by wells, which might be used for comparison. Experience soon proved that family decline curves were seldom of value and generally quite worthless for estimating well potentials in a curtailed field.

For some time after the beginning of curtailment, potentials of individual wells were estimated by projecting the past decline curves. The famous February flow test proved that greater consideration had to be given to the present conditions of wells than to past history.

During the flow tests, it developed that the potential of the Elwood and Ventura Avenue fields had been greatly underestimated while the potentials of Santa Fe Springs and Long Beach had been considerably overrated. The vast differences in the development methods of these fields accounted for the errors in potential. In effect the decline of the deep zone wells at Santa Fe Springs had been much more rapid than the early history of the first wells would indicate. As a matter of fact, it could be seen that in certain areas of the field the completion of every additional well accelerated the decline of earlier wells.

Determination of Potentials

As mentioned, the initial potential of a new well, or of a well that has had some radical change in production methods, is determined by averaging the production for the last four days of a five-day test during which the well is produced at any rate deemed safe by the owner. The

initial potential thus established serves as a basis of proration until the next adjustment, when the initial potential is subjected to some apparent or assumed rate of decline. The subsequent estimation of the potential of such a well is discussed in succeeding paragraphs.

It was soon discovered that if satisfactory production records were to be kept, and if potentials were to be estimated with any degree of accuracy, production graphs for all leases and for all large or recently completed wells would have to be prepared and maintained. The original construction of these graphs and their constant maintenance involves a lot of work but the results obtained have more than justified the adoption of graphical records of production.

No data appear on a production graph that can reasonably be omitted. Thus the production graphs of some leases are very simple but the graph of a large well, of necessity, may be fairly complex. Extreme examples of different types of production graphs are presented here (Figs. 2 to 5).

With past history and family curves both proved unreliable in the estimation of potentials, it became necessary to devise some more accurate means of estimating the potential of wells having an irregular history. Any such method had to be based upon the initial flow test in some way, as that was the one definite fact which needed no interpretation. Unfortunately, the initial flow test potential, while established accurately enough, was often conducted under conditions of flow that would not long persist, and in such a manner that continued production in that manner would be neither wise nor safe.

Thus the problem of estimating the potential of wells that had been producing under severe curtailment for several months was a real one. The first step was to establish a classification under which wells and leases could be arranged approximately in order of the difficulty encountered in estimating their future potentials. As a result of this classification, it was found that about 80 per cent. of all wells considered offered little or no difficulty. These were wells that showed such graphical regularity of production that their respective potentials could be calculated with a close degree of accuracy at least three months in advance. The remaining 20 per cent. of the wells considered involved more consideration and work than did the 80 per cent., and the estimates obtained were much less accurate.

As is well known, it is mathematically possible to resolve the normal decline curve of a well into several empirical formulas representing as many different types of natural curves, of which those representing the so-called hyperbolic and exponential type are the most common, although there are others equally accurate but somewhat more cumbersome of application. There are some reasons for using some of these curves, because they reflect some of the natural mechanics governing oil production, but most of them approximate some natural curve *only by coincidence.*

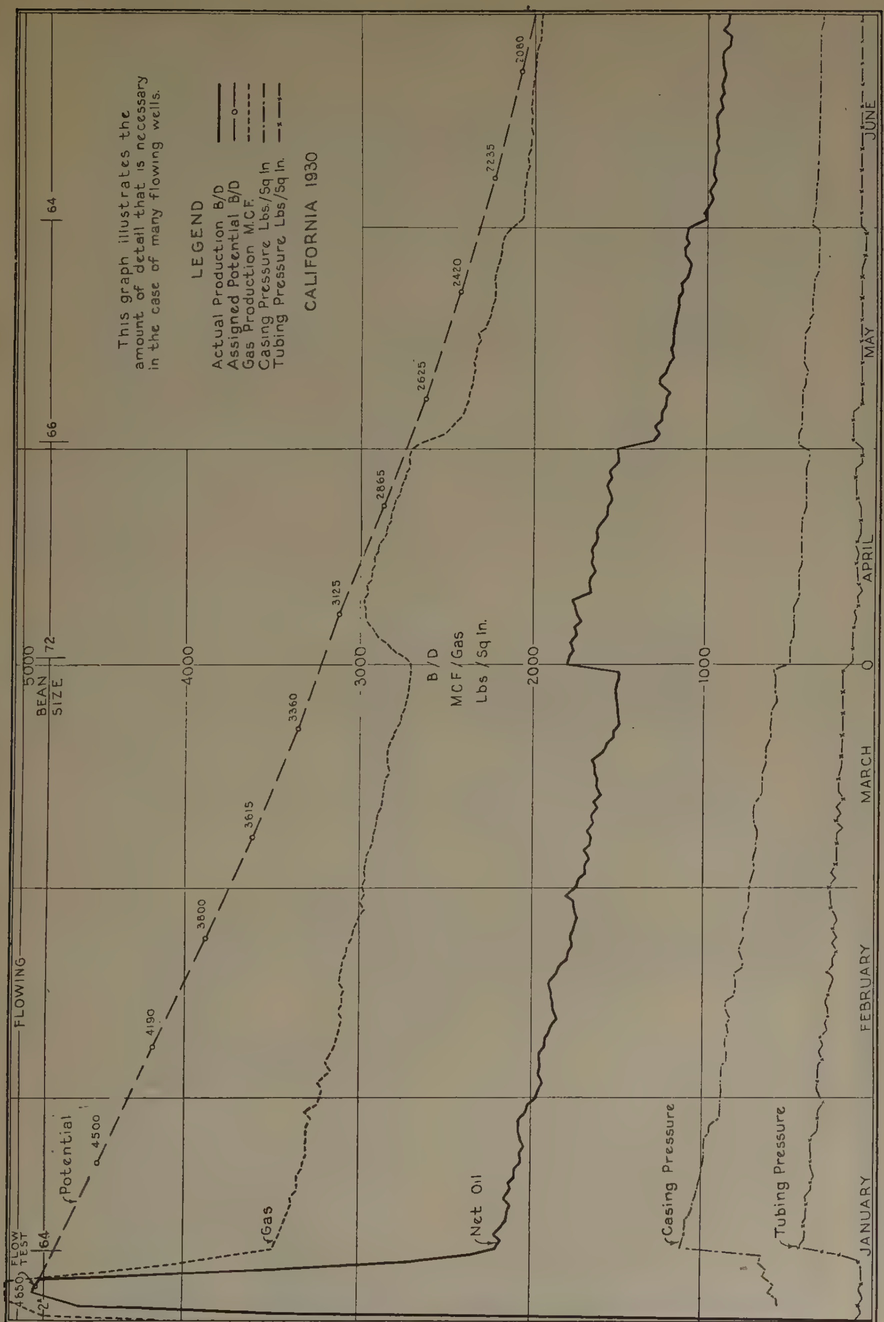

FIG. 2.—TYPICAL PRODUCTION GRAPH OF INDIVIDUAL WELL.

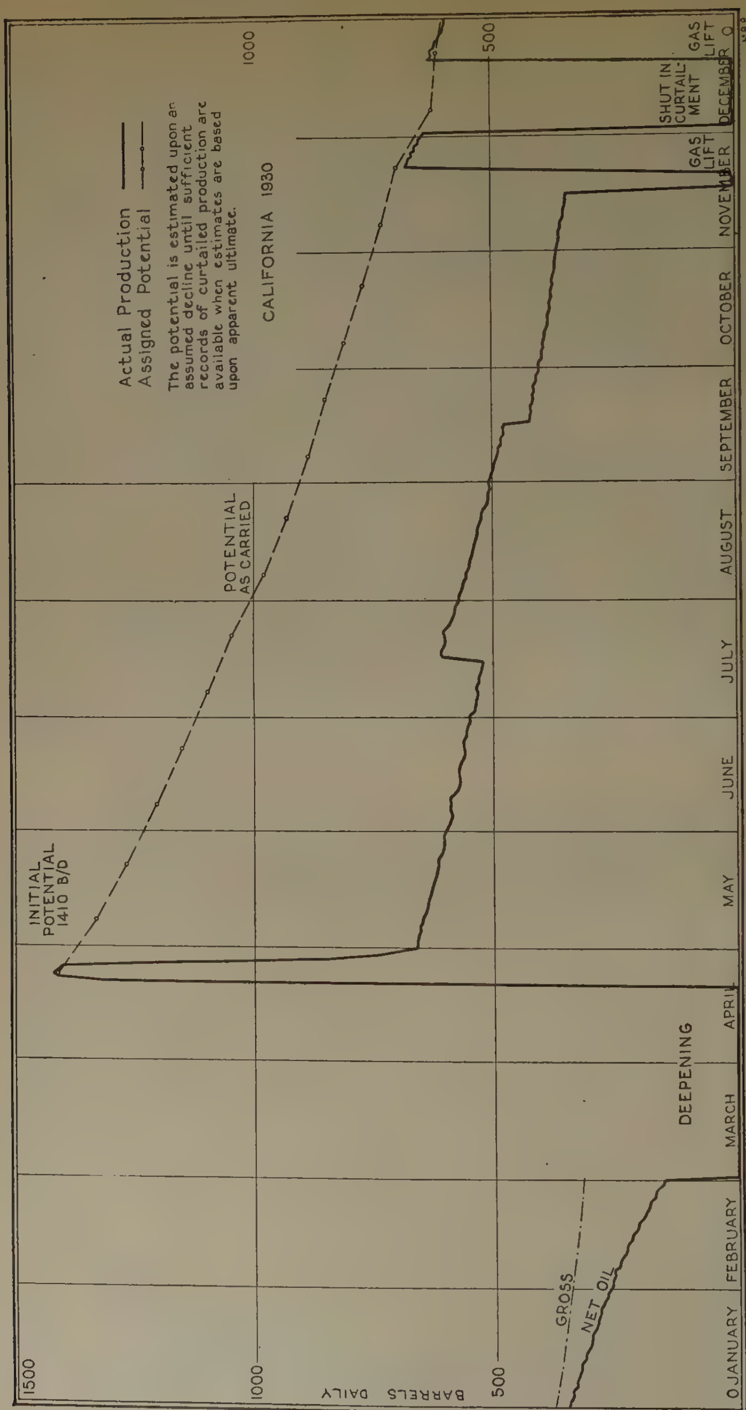

FIG. 3.—POTENTIAL PROCEDURE GOVERNING A WELL THAT HAS NO NORMAL PRODUCTION.

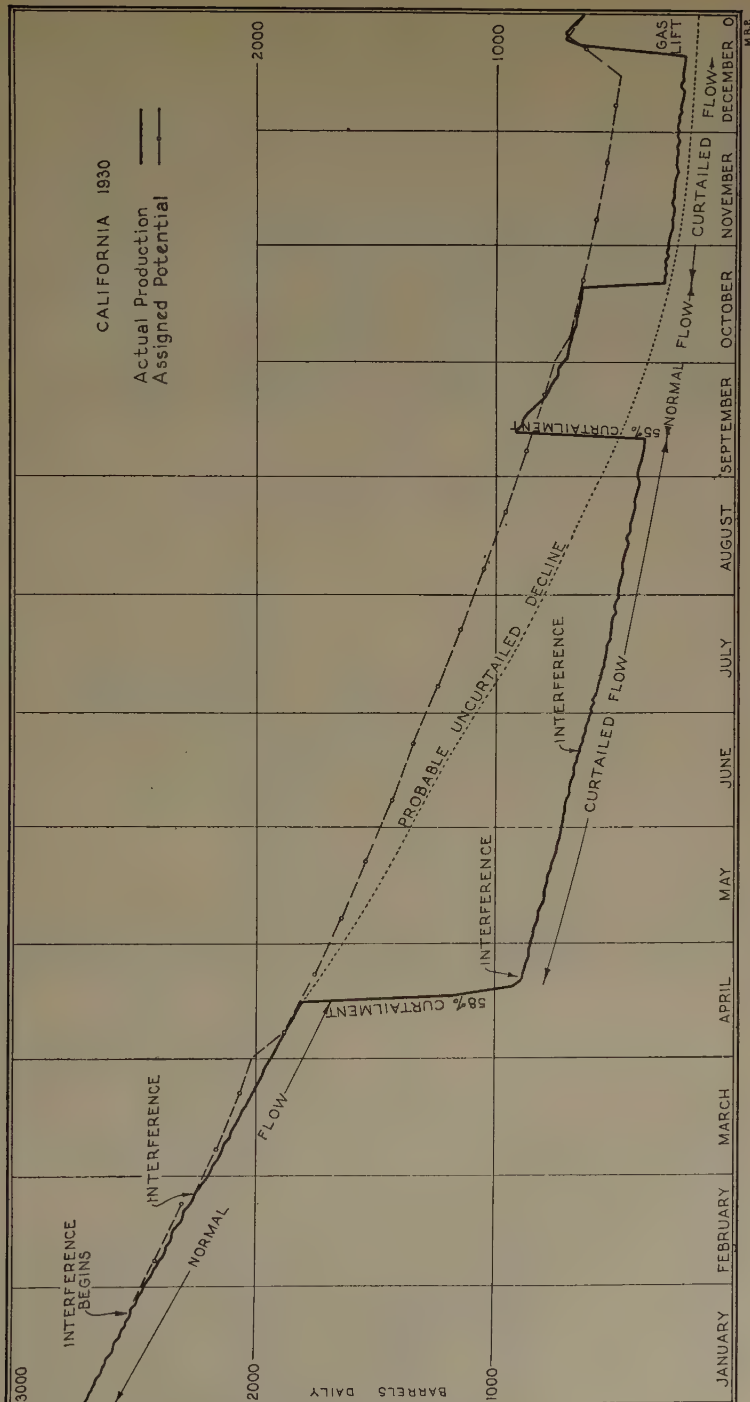

FIG. 4.—TYPICAL WELL PERFORMANCE DURING CURTAILMENT.

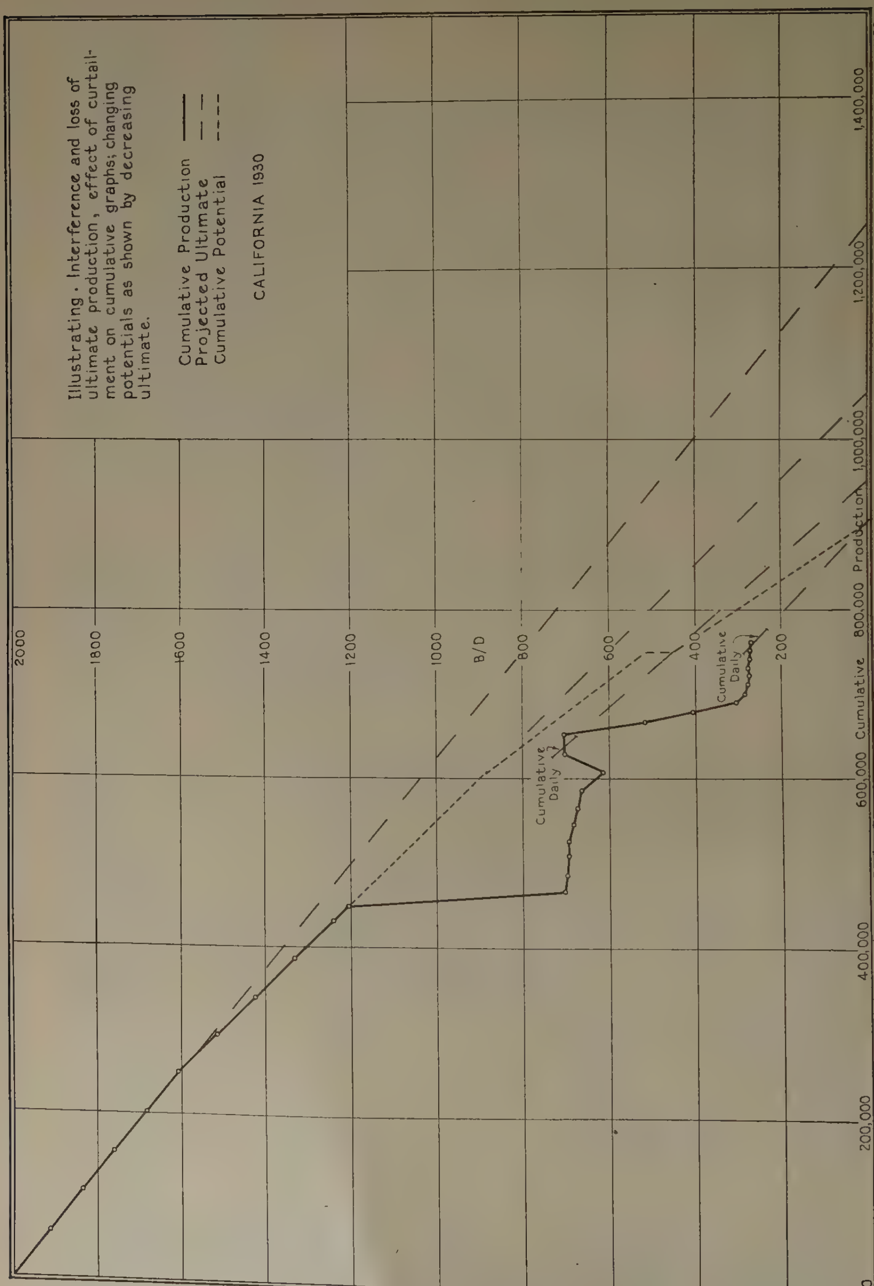

FIG. 5.—CUMULATIVE PRODUCTION CHART.

Since so many variables enter into the natural decline of a well, it seems doubtful whether any empirical formula can be developed to represent a well's decline for longer than the limited periods during which mechanical and underground conditions remain practically unaltered.

Since accurate short-time estimates were required rather than long-time approximations, it became necessary to select some formula that could be applied readily and with little calculation. Obviously enough the simplified exponential formula represents the most practicable one available for the 80 per cent. majority of the wells considered. The operation of the exponential formula requires only the average normal production of two periods of any convenient length from a few days to several months. The same results may be obtained by the use of several different formulas, which may be made as complicated as desired but which are given here in their simplest form:

$$c = \frac{b}{f} \qquad \left(f = \frac{a}{b} = \frac{1}{r} \text{ and } r = \frac{b}{a} = \frac{1}{f}\right)$$

$$c = \frac{b^2}{a}$$

$$c = b \cdot r^n$$

Where c = required potential or estimated daily average for next period.
b = average daily production of present period.
a = average daily production of previous period.
f = decremental factor.

In this instance, successive equal intervals of average production are assumed but intermittent periods of unequal length are easily used by making appropriate modifications of the formula. This formula can be developed into a formula for calculating the recoverable oil remaining as of any given time.

$$\text{Future production} = \frac{d(a - z)}{1 - r}$$

Where d = number of days in periods used.
z = minimum commercial daily production.
a and r = as above.

Thus a well showing an average production of 150 bbl. daily during January and a normal average of 125 bbl. daily for June might be expected to average 120.5 bbl. daily during July, according to the brief calculation:

$$\text{July potential} = \frac{125}{\sqrt[5]{150/125}} = \frac{125}{\sqrt[5]{1.2}} = \frac{125}{1.037} = 120.5 \text{ bbl. per day.}$$

Assuming that 10 bbl. daily is the minimum commercial production of the well, the recoverable oil remaining as of June 1 would be:

$$\frac{30(125-10)}{\left(1-\frac{1}{1.037}\right)} = \frac{30(125-10)}{(1-.96423)} = \frac{3450}{.03577} = 96{,}450 \text{ bbl.}$$

The expected life of the well after June 1 would be 70 months, or nearly six years. The total life and total ultimate production expected from the well may be obtained by adding past life and production to estimated future life and production.

In applying the procedure outlined, it must be remembered that the formulas given apply only to settled production, which may be considered as coming from wells showing an average monthly decline of less than 5 per cent. In practice it has been found that the ultimate production as estimated was consistently a trifle lower than the ultimate obtained, although theoretical considerations indicate that the actual production might slightly exceed the estimates.

Principles Governing Potentials

As a result of analyzing the production graphs of hundreds of wells under every conceivable kind of control and with every degree of curtailment, several principles governing the establishment of well potentials were developed. The more important of these principles may be mentioned.

1. The decline of a flowing well free from serious interference is a function of the differential pressure (*i.e.*, difference between effective formation pressure and the back-pressure) and is subject to variation within wide limits by mechanical control.

2. The potential production of a well at any time and under uniform physical conditions depends upon its total past production as compared with its ultimate production rather than upon the rate of past production.

The meaning of the first principle is that within wide limits the producer may govern the rate of decline of his well by mechanical manipulation. The second principle says that the potential production of a well that has produced a certain amount of oil under curtailed conditions in a given time is the same as if the well had produced the same amount of oil under normal conditions and in a much shorter time. This may be considered as a corollary to the law of equal expectations.

An additional principle, which appears to be true but is not yet proved, is:

3. The ultimate production of a well having little or no competition may be considerably increased by limiting the well to a low rate of decline during its flowing life.

This principle is clearly indicated at present but it is too soon to say when edge-water encroachment will terminate the production from several wells under observation.

In practice it was found that the second principle could be applied only to isolated wells because well interference in a closely drilled field is so serious that any well may easily lose a large proportion of its original ultimate production to competing wells. It was noted that in a great many cases the potential production of wells in competition declined at almost exactly the same rate at which their actual curtailed production declined. Thus a well with a potential of 1000 bbl. daily, and with a monthly decline of 10 per cent. under curtailment, would be given the same percentage decline in potential. This was found to be true in so many cases that the principle was applied to all wells except those obviously irregular.

The method of estimating and the assignment of potentials to wells under widely different conditions is illustrated in Figs. 1 to 6. The variable performance of the wells under curtailment is also shown. One feature worthy of note is that the usual method of curtailing gas-lift wells is to produce them at capacity until their total monthly allowable production is obtained and then shut them in for the remainder of the month. This is because the daily allowable is usually far less than the minimum amount that the well will produce by gas-lift. Frequently, also, a potential is established on gas-lift, but the allowable production based on such a potential may be obtained by natural flow or by pumping.

The gas-oil ratio of a flowing well has a considerable bearing on the curtailment problem of that well. One of the results of the curtailment program has been the concerted effort of many operators to reduce the gas-oil ratios of curtailed wells. The common tendency of flowing wells to increase their gas-oil ratio if left undisturbed for some time is well known. It is difficult to avoid this increase in the gas-oil ratio except by careful and frequent adjustment of mechanical conditions and by severe curtailment during the early life of the well.

It is apparent that this increase in the gas-oil ratio is due to the removal of fluid from the well faster than it can flow through the sand to the well. This results in an area of local impoverishment surrounding the well, with the pressure gradient increasing rapidly in all directions away from the well. The farther gas has to travel to enter a well, the less oil comes with it. This is because of the higher mobility of gas, together with its tendency toward by-passing and slippage in the formation.

Obviously, the solution of this problem is to maintain a low pressure gradient in the formation and thereby hold the drainage area in near equilibrium. In theory, oil should be removed from fields under hydraulic control only as fast as edge water can encroach to take its place.

Unfortunately, we know so little about the source, effect and rate of movement of edge water that we cannot base our production upon it. Particularly should we know more about the components of edge-water pressure—how much of the pressure is due to hydrostatic head, how much to rock pressure and how much to gas accumulation. Its rate of movement depends upon the effective pressure and upon formation friction, and also upon its source.

Unable to use edge-water encroachment as an index for our rate of production, we are forced to cast about in search of some arbitrary standard to guide us. In this search we may consider that it is our purpose to derive the maximum practicable amount of work from all gas originally present in the reservoir. Conditions vary so much between fields and between wells in a field that it is difficult to make a statement as to what constitutes efficient gas utilization. However, a few generalizations may be made as follows:

1. The gas-oil ratio of an individual well should not exceed the average ratio of the zone or field. Wells exceeding this average should be adjusted or shut in completely if not subject to improvement.

2. Production should be obtained by the most efficient mechanical means. Thus a well may be flowed through the casing at one stage of its life and through tubing at another stage, or control may be entirely by tubing depth, tapered tubing or bottom-hole beans. Except for curtailment purposes there should be no back-pressure on properly tapered tubing or on tubing having the correct bottom bean. High-pressure gas from wells in one zone has been taken directly from the trap to flow wells in zones requiring gas-lift.

3. The decline curve of a well should not be allowed to become of the power function or hyperbolic type, for such a curve in a field under hydraulic control indicates that gas is doing more work than is necessary.

If hydraulic control is lacking or negligible, the decline curve should be not less than isothermal in type, which is a power function curve of the formula $k = x^1y$ in which the product of the production and the time element is always constant. The value of n in the formula $x^ny = k$ should be kept as high as possible. However, in all possible cases, a curve showing a constant percentage of decline with a low rate is preferable to curves that indicate inefficient utilization of gas.

It is not always easy to recognize the type of natural curve represented by a well's decline, so the following directions may be found useful:

Given: The average daily production of three successive equal intervals of flow under normal conditions.

Required: To determine the type of curve represented by the well's decline.

Procedure: Substitute known values for a and c in the following equations and solve for b.

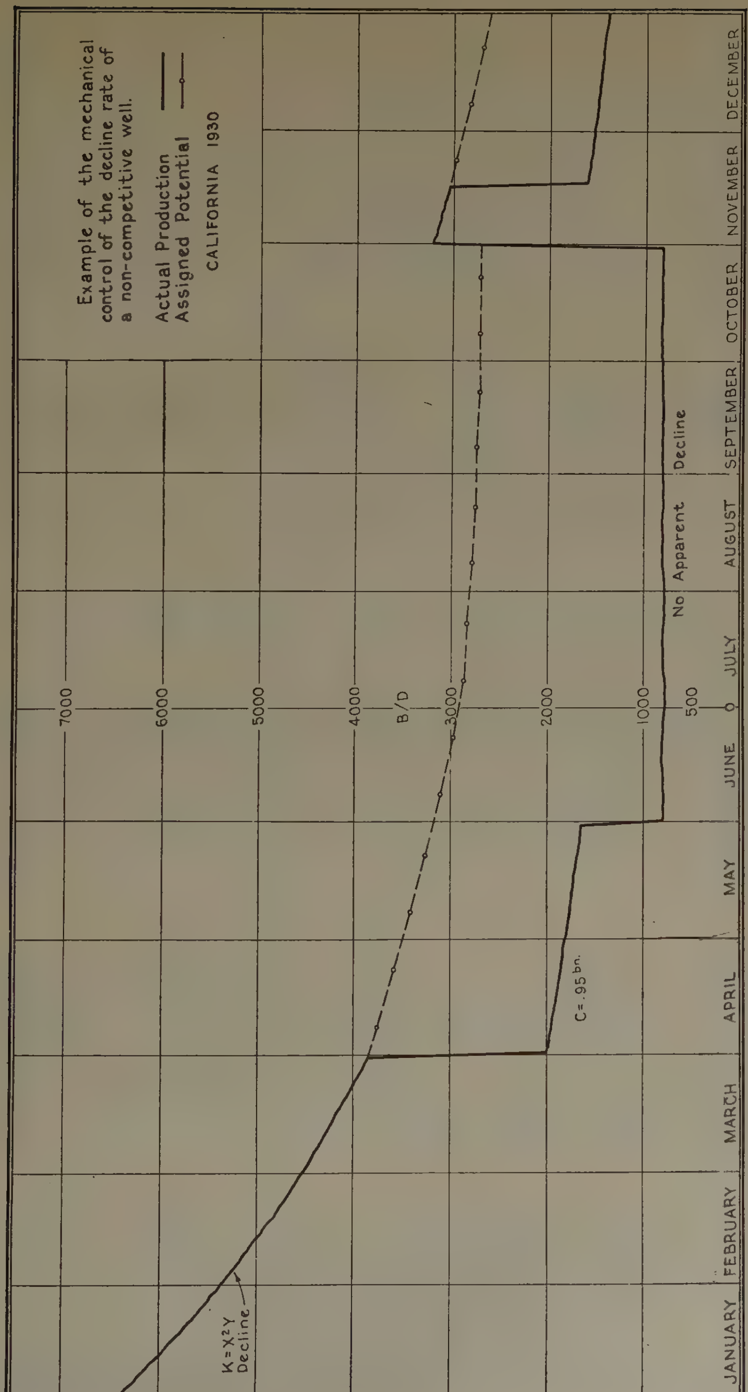

FIG. 6.—CONTROL OF DECLINE.

1. $b = \frac{a + c}{2} = \begin{cases} \text{Arithmetic decline.} \\ \text{Constant decrement decline.} \end{cases}$

2. $b = \sqrt{ac} = \begin{cases} \text{Geometric decline.} \\ \text{Constant rate decline.} \\ \text{Exponential decline.} \end{cases}$

3. $b = \dfrac{2ac}{a + c} = \begin{cases} \text{Harmonic decline.} \\ \text{Isothermal decline.} \end{cases}$

4. $b = \dfrac{a + c}{(a + c) - \dfrac{(2ac)}{a + c}} = \begin{cases} \text{Basic decline.} \\ \text{Fractional power decline.} \end{cases}$

Result: The decline curve of the well may be considered as being of the type named with the equation, giving a calculated value for b most nearly equal to the actual value.

Ninety per cent. of all well-decline curves fall between type 2 and 3 and may be considered either as power function curves with high n values or as double-exponent curves. Between types 2 and 3, and between types 3 and 4, many other empirical equations may be developed. For the greatest flowing production as well as for the largest commercial ultimate, the decline curve of a well should be held closely to the geometric decline type of curve (Fig. 6).

It is interesting to note that the fields where conditions most nearly approach those of unit operation are the fields that have had the fewest curtailment difficulties and are the least affected by curtailment. It follows, of course, that the periodic need of balancing production against demand is another argument in favor of unit operation, which provides the easiest and most efficient method of bringing about such a balance.

Future of Curtailment

The oil industry has now demonstrated that although it is impossible to increase demand as rapidly as the supply is often increased, it is possible to adjust cooperatively the supply to the demand by means of proration. Other industries even now are following the same course, and it seems probable that the time will soon come when huge stocks of surplus commodities will be unknown because they will not be created in excess of normal needs.

The prosperity of the 80,000 employees of and the 500,000 investors in the California oil industry is so dependent upon stable conditions of production and price that it now seems probable that oil curtailment in some form will continue until storage oil is reduced by one-half and until the normal production of the state closely approximates current demand.

Aside from its economic value, curtailment has given us a better knowledge of some of the factors affecting the production of oil and the

management of oil fields. Some of these have been briefly touched upon in this paper; others must await further investigation. Unfortunately, as is the case with many other advances, the full effect of more efficient production methods can be realized only under ideal conditions of development, and such ideal conditions are entirely too rare. It seems possible, however, that the growing spirit of cooperation among oil producers as manifested by the success of voluntary proration may lead eventually to the cooperative development and production of oil fields on such an efficient basis that restricted production will become the rule rather than a necessity.

Acknowledgments

Acknowledgment is hereby made of the valuable suggestions and assistance received from Joseph Jensen, D. R. Roberts, F. A. Graser and M. R. Peterson in the preparation of this paper.

DISCUSSION

(John F. Dodge presiding)

R. R. Boyd,* Los Angeles, Calif.—Mr. Allen referred to the Engineers' Advisory Committee, which was called a fact-finding committee during the February flow test. This committee shortly developed into an actual engineering advisory committee and was so named.

In regard to the allotted production for the State of California set by President Hoover's commission at 609,000 bbl., and adopted by this state, it might be interesting to discuss how this figure was first obtained. I am unfamiliar with the reasoning, but apparently they arrived at 609,000 bbl. on the basis of the demand in the natural trade territory of California. After curtailment was placed in effect, this figure, it shortly developed, was too high and the question was brought up before the general committee whether it would not be advisable to cut to 550,000 bbl. daily. This precipitated a great deal of discussion and finally resulted in the appointment of a Committee on Economics, which was to go into the statistical situation of the oil industry and determine a figure to be recommended as the correct figure for the curtailment allotment.

This committee was headed by Earl Wagy. It did a great deal of work in collecting statistics on stocks and production and demand for California. The sources of supply were investigated, decline curves set up and the California production was predicted. The question of demand was gone into in the same way. Statistics were collected for the demand over a long period of years and the trend was ascertained. Stocks on hand were canvassed and the quantity of the different petroleum products that was desirable to have on hand to meet refinery and market conditions was determined.

After these quantities were decided, the committee figured backwards and arrived at 596,000 bbl. as the daily production. Curtailment never was brought down to 596,000 bbl., and, in addition, the anticipated consumption for the summer months of the present year fell short of that which had been predicted, owing to the economic condition of the country. Also, the runs to cracking stills increased. It was discovered by the Economic Committee that the element to be overcome in this curtailment program was not supply of gasoline or refinable crudes but the heavier oils

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* Production Engineer, Richfield Oil Co. of California.

known as gas oils and fuel oils. These stocks had been continually building up over a great many years and no hope was in sight except through cracking them and reducing them to marketable products. Our use of fuel oils was declining, because of competition in natural gas due to the completion of gas lines to San Francisco and to the anticipated gas lines into Arizona from New Mexico, and to the restriction of other markets. Heretofore a certain figure had been set up for the probable run to cracking stills. On account of the economic situation the companies found it desirable to crack a larger proportion of the oil. Therefore their runs to cracking stills increased, cutting down the amount of refinable crude that could be handled.

In reviewing the situation in September this situation was analyzed and it was found that the change in conditions indicated that 550,000 bbl. was more nearly a correct figure than 596,000.

D. Dana,* Los Angeles, Calif.—In many areas a newly completed well suffers many interruptions in flow for a period of months before being placed upon steady production under constant conditions at the well head.

R. E. Allen.—That is one of the most difficult features, and presents the most difficult problem of estimating potential of wells. Everything has to be taken into consideration in cases of that kind, such as variability of gas pressure and orifice. That is why the record shown here is necessarily so incomplete. Often the critical information will not appear in the production of the well itself; it will appear in the accessory information.

S. C. Herold,† Los Angeles, Calif.—It appears that some of our ideas concerning the effects of proration are based on a misinterpretation of the volume-rate curve. This is a dangerous curve to project into the future unless one understands it. A change in the direction of this curve on the plat requires a change in the zero point for the horizontal scale. Unless this modification is made, an erroneous interpretation regarding the effects of proration necessarily follows. The matter rests upon the theoretical mechanics of the curve.

R. R. Boyd.—Mr. Allen's paper enunciates three principles. He does not seem to be quite sure of the third one, but it is to the effect that the ultimate production of wells has been increased through curtailment. I am inclined to say very strongly that we have many wells that have been definitely improved and that because of curtailment our ultimate production will be larger.

E. L. Davis,‡ Long Beach, Calif.—We have no definite results. In some wells production has been noticeably sustained but in others the effect has been detrimental. We cannot be sure what the average result would be.

J. F. Dodge,§ Los Angeles, Calif.—Of course, we are dealing with a condition where perhaps curtailment is not applied equally over the field, either through unavoidable errors in the assignment of potential or the inability to force operators to follow curtailment, and so we do not have perfect conditions from which to judge whether or not curtailment has been beneficial.

R. E. Allen.—The principle Mr. Boyd mentioned was qualified by saying wells without serious interference will have their ultimate increased by proper curtailment. That curtailment does not necessarily mean enforced curtailment but includes also any control resulting in regulation of back-pressure.

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Proration in Texas

By David Donoghue,* Fort Worth, Texas

(New York Meeting, February, 1931)

The efforts towards curtailment in Texas have been successful, despite the great area covered and the wide variety of oils offered. There are, of course, examples of noncooperation, perhaps of absolute indifference, but of such it can at least be said that they have benefited from the restrictions imposed elsewhere.

The prevention of waste is the legal background for proration in Texas. The legislature in 1899 passed the first laws to prevent waste of oil and gas. Subsequent legislatures, especially those of 1905, 1913 and 1917, undertook to regulate the development and transportation of oil and gas to the end that waste would not occur. In 1917 a constitutional amendment was submitted to the people, providing that natural resources of the state should be conserved and requiring that the legislature pass appropriate laws. This amendment was adopted, and the Acts of 1919 and 1929 have been passed, and these have had the effect of making a rather elaborate plan for the conservation of oil and gas and their protection against waste. In 1930 the new pipe line act, designed to provide for ratable purchases, was passed.

The administration of these laws has been placed under the Oil and Gas Division of the Railroad Commission of Texas. The Commission can only consider actual waste, not economic waste. The various proration plans in use in the state, while differing in efficiency, are based on engineering principles. In the proration of flush fields, the limiting of drilling and the steady production of oil under restriction are the principal points involved, and these methods are entirely different from those which prevailed until recently in the Oklahoma City Pool, where apparently nothing beyond the restriction of production on a time basis was attempted.

There is little to say in defense of proration in the older and smaller producing areas in Texas, except that, inasmuch as the market outlet has been reduced, proration distributes the market ratably among the producers.

Work of Central Proration Committee

In the early part of 1930 the overproduction situation became acute, and, at the request of the Railroad Commission, a committee was formed composed of representatives of the Texas Division of the Mid-Continent

* Technical Advisor to Central Proration Committee of Texas.

Oil and Gas Assn., of the Independent Producers Assn. of Texas, and buyers of crude. This committee now functions as the Central Proration Committee.

A survey of the situation was made and a report was compiled setting forth supply and demand of crude oil in each of the districts of the state. The figures assembled indicated a supply of 76,000 bbl. in excess of demand. To this excess an additional 50,000 bbl. was added, and it was proposed that production should be cut from 863,000 to 737,000 bbl. per day. A report to the Railroad Commission was prepared, recommending that production in each district be reduced in varying amounts, depending upon market demand and other factors. After several hearings the Railroad Commission issued an order, effective August 27, directing that production be reduced to 750,000 bbl. per day. Committees in each district and field were appointed where they had not already been organized, and efforts were made to persuade all operators to adopt proration methods that would receive the approval of the Railroad Commission. Where this was successful in whole or in part, an umpire was selected and given an official status by confirmation by the Railroad Commission.

The first order was for a period of 90 days. In a general way it was successful. The second order, effective for a period of 60 days, provided for a maximum production of 680,238 bbl. per day. After operators, pipe lines and buyers began to understand the situation better and increased their cooperative efforts, restrictions gradually resulted; and at the end of the year 1930, production in Texas had decreased to approximately 660,000 bbl. per day. The third order, extending proration to April 1, 1931, sets the production of the state at 644,253 barrels.

Organized curtailment in Texas had its beginning in the Yates pool, where on Oct. 1, 1927, production was prorated according to total potential capacity of the wells. This proved unsatisfactory and finally resulted in July, 1928, in the scheme which we now refer to as the Yates plan. This is the most satisfactory, certainly the most successful, plan that has yet been tried. Producing leases are divided into 100-acre units; 25 per cent. of the pipe line outlet is divided equally among these units and the remaining 75 per cent. is prorated on a basis of average potential production per unit. This plan serves to keep drilling as low as possible, gives small wells a chance to pay out and has sufficient flexibility to be applied to almost any newly developed field and to be adapted to local conditions.[1] Proration methods in other Texas fields have been described elsewhere[2] and it is not necessary to go into details concerning them here. The methods are summarized in Table 1.

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[1] H. C. Hardison: Proration of Yates Pool, Pecos County, Texas. See page 74.

[2] F. H. Lahee: Unitization in Arkansas, Louisiana, Texas and New Mexico. *Trans.* A. I. M. E., Petr. Dev. and Tech. (1930) 39.

J. E. Thomas: Production Curtailment in Texas. *Proc.* 9th Annual Meeting Amer. Petr. Inst., Sec. 3, 5.

Factors of Successful Proration Plans

The factors that enter into the actual operation of any proration method are: nominations, potentials, methods of gaging, exemptions and pipe line connections.

Nominations may be defined as the daily amount of oil that a company or individual will buy or take from a given area or from a field or district. The total of the nominations, however, is not the amount of oil that can really be taken from a field under proration, because some companies with pipe line affiliations will not buy oil other than that produced upon their own or certain designated leases. The outlet of a field, therefore, is determined by the nominations of the companies that are willing to buy proratedly from the free oil that is available.

Potentials in prorated areas are for purposes of proration only, any other use presumes ignorance or deception. By none of the methods of testing wells now in use can we hope to arrive at a true 24-hr. gage. The very reason for the gage will cause operators to put wells in shape to make their best showing. In fields that have large flush production the problem of handling oil produced by a few hours open flow has to be taken into consideration. Obviously, the gages are merely yardsticks for comparison of one well or lease with another, and not for comparison of one field with another.

The success of any proration scheme depends largely upon the ability and discretion of the field umpire. Exemptions have to be made, and as local conditions govern these matters, no hard and fast rules can be passed. Wells making excessively large quantities of water often have to be allowed to produce more than adjoining wells. On the other hand, wells wasting an excessively large amount of gas should be shut in.

An exemption known as the Marginal Well Rule is used in some areas, but in other areas, this rule has been dispensed with on account of difficulties of administration. The protection of wells making small amounts of oil is sound conservation. Some figure has to be selected in each area in order to designate the marginal wells. The depths of wells are taken into consideration and this marginal well limit, as it is known, is applied to all wells and the excess above this limit is prorated. Thus discrimination, if it does exist in favor of small wells, is minimized.

The greatest difficulties encountered in proration have been in connection with obtaining a pipe line outlet for every well. These difficulties are more pronounced in the older areas, such as West Central Texas, North Texas and the Panhandle. Pipe lines can hardly afford to lay several miles of line in order to obtain a small amount of oil. In some instances where buyers have withdrawn from a field, it appears that many producers will be without connections unless someone purchases the lines of the withdrawing company. These difficulties have

TABLE 1.—*Methods of Proration in Texas* [a]

District	Number of Producing Wells	Production as of Feb. 7, 1931, Bbl. per Day	Maximum Allowed by R.R. Commission, Bbl. per Day	Potential for Proration Purposes Only,[b] Bbl. per Day	Methods of Gaging	Method of Proration
Panhandle	1,952	57,000	40,000	142,457	48-hr. test using last 24 hr.	Prorated on basis of total potential.
North Texas	14,265	53,000	58,144	77,753		Prorated on basis of excess of total lease potential above marginal exemption of 4 bbl. per well for wells up to 2000 ft. deep.
North Young Co.	1,100	9,850	5,749	17,249		
West Central Texas	8,661	24,400	25,000	44,297		Prorated on basis of excess of total lease potential above a marginal exemption of 4 bbl. per well for wells up to 2000 ft. deep; 8 bbl. for wells from 2000 to 3300 ft. deep; 14 bbl. for wells over 3300 ft. deep.
West Texas	2,940	245,600	245,927			Prorated on basis of excess of total potential above a marginal exemption per well of 12 barrels.
Crane-Upton	593	24,450	29,000	48,189		
Ector	79	5,500	8,091 (Nominations)		25 hr. open flow, 5 per cent. cut each period for 3 months.	Each lease is divided into 40-acre units, but a lease of less than 40 is considered a unit. A tract of less than 40 acres adjoining a full unit, tract and unit belonging to the same operator, is included with the unit on the basis of acreage; for instance, a lease of 50 acres is considered 1.25 unit. 25 per cent. of outlet is divided equally among units; 75 per cent. of outlet is divided on basis of average unit potential.
Howard-Glasscock	535	26,900	26,700 (Nominations)	78,861	2-hr. gage using second hour's figure for computing.	Prorated on a basis of 12 bbl. minimum per well for wells producing from the 1300 and 1800-ft. sands, and a 50-bbl. allowance to be made on all wells producing from the 2200, 2500 and 3000-ft. sands, the remainder of the pipe line outlet to be allocated to all wells on the basis of excess potential, the average potential to apply to the Phillips-Coffee field and total potential to apply to the Chalk, Dora Roberts and Henshaw fields, the Umpire to make allowances for water wells when necessary.
Winkler	534	50,900	60,000	113,615	1 hr. open flow.	Each lease is divided into 40-acre units. A lease of less than 40 acres is considered a fractional unit on basis of ratio of acreage in lease to full unit. 50 per cent. of outlet is divided equally among units; 50 per cent. of outlet is divided on a basis of total unit potential.
Yates[c]	400	90,950	89,500	5,508,696	1 hr. open flow, thereafter pressures and water taken into consideration.	Each lease is divided into 100-acre units, but a lease of less than 40 acres is considered a unit. A tract of less than 100 acres adjoining a full unit, tract and unit belonging to the same operator, is included with the unit on a basis of acreage; for instance, a lease of 160 acres is considered 1.6 units. 25 per cent. of outlet is divided equally among units; 75 per cent. of outlet is divided on a basis of average unit potential. Seepage oil and oil from shallow pits is exempted in order to keep from polluting the Pecos River.

East Central Texas	1,204	49,350	38,735			
Van	187	29,000	30,000 Feb. 1 35,000 Mar. 1	393,842	Through 1 1/16 in. choke and 2½-in. tubing for 3-hr. period; last 2 hr. used.	Each lease is divided into 20-acre units. A lease of less than 40 acres is considered a fractional unit. 100 per cent. of outlet is divided on a basis of average potential. On fractional units the average potential is reduced to the ratio that the acreage in the tract bears to a full unit.
Southwest Texas	3,581	75,650	77,447			
Chapman	71	5,850				Prorated on basis of total potential.
Darst Creek	248	32,200	30,000	160,262	8-hr. gage. Field divided into 3 zones.	Prorated on basis of total potential. Exemption on 100 bbl. per lease.
Salt Flat	320	11,400	15,333 (80% of potential)	19,153	24-hr. gage.	Prorated on basis of total potential.
Gulf Coast	2,696	162,150	155,000			
Racoon Bend	105	8,000	10,000			Gas-oil ratio.
Sugarland	77	12,300	12,400			Gas-oil ratio.
Bee County	44	7,650	8,450 } 600 }	12,374	6-hr. flow; last 3 hr. used as gage.	No air-gas lift allowed. Maximum gas-oil ratio 2000 cu. ft. per barrel. Ray-McKinney pool maximum of 3300 bbl. per day from pool and of 300 bbl. per well. Cosden pool maximum of 1250 bbl. per day from pool and 225 bbl. per well. Pettus town site maximum of 4500 bbl. per day from pool on basis of total potentials.
Totals	35,299	677,000	644,253			

[a] D. Donoghue: Report No. 6 to Central Proration Committee, Ft. Worth ed., (Jan. 8, 1931) **4**, 11–13.

[b] Potentials in prorated areas are for the purposes of proration only; any other use presumes ignorance or deception.

[c] Hobbs, New Mexico has 134 wells, an allowable production of 31,475 bbl., a potential for proration purposes of 1,081,578 bbl., and the proration method in the Yates plan with 40-acre units. New gage being taken. Proration extended 6 months from 1/10/31.

been solved to some extent by getting the producers either to lay their own lines to some point convenient to the buyers' pipe lines or to pay the gathering charge to the pipe line with which their leases were connected, thus securing transportation to the buyers' pipe line system. This, of course, means that a producer will be put to some expense, but it is certainly better that he should net 10¢ or 20¢ per barrel less than the posted price under proration than perhaps 25¢ to 50¢ less than the posted price without proration. It is to be regretted that it is necessary to prorate these old producing areas in such drastic manner; and the very fact that it is done should impress upon the skeptics the real need for proration in the newly developed flush areas that are appearing in other portions of the state.

It is noticeable that in discussing proration in Texas various articles written during the past few months have taken Winkler County as an example. Among those connected with the oil business, it has always been recognized that due to the methods of gaging, Winkler County potentials have been high; and that for many months Winkler County has produced practically all of the oil that it could produce. It might be said that Winkler County has paid well for this privilege of producing at capacity. The field is now making about 55,000 bbl. of oil and about 900,000 bbl. of water per day. Its production to date has been about 135,000,000 bbl. of oil and much of this was sold at 40¢ per barrel. With reasonable restrictions, it is safe to say that the field would have made ultimately at least 50 per cent. more than it will under present conditions. A good plan was not adopted in the first place; and an injunction which some operators obtained further complicated matters and prevented effective proration. The Winkler plan provided for 40-acre units with 50 per cent. of the outlet divided equally among units, and the other 50 per cent. outlet divided on the basis of total unit potential. This plan does not limit drilling, which, of course, is one of the most important phases of any proration scheme. A well-developed plan, such as that at Yates, brings into use the most efficient methods of operation. Besides restraining the rate of production, it conserves gas, controls water, increases flowing life of wells, increases amount of oil ultimately recovered, reduces cost per barrel of lifting oil, decreases cost of equipment necessary to care for flush production at the surface, and has a tendency to maintain price. Proration is not only a restraint on production but also a restraint on drilling, in which, after all, the greatest investment is made.

That the effects of proration are beneficial is shown by profits made in Yates and Ector counties and in the favorable position of the Van field in East Texas. In fact, anything that has a tendency to eliminate boom conditions and make the producing of oil more orderly will also increase the profits, and proration has made great strides in this direction.

With the bringing in of several wells in Rusk County and in Gregg County in East Texas, apparently good for 2000 to 10,000 bbl. per day in an area where lands are cut up into numerous small tracts and titles are somewhat involved, a threatening condition appears to be developing. However, with market conditions as they are it is probable that many of the operators who are producing oil for the first time will find that selling oil is not easy; and if a sensible proration scheme is not adopted in the beginning it is probable that more drastic regulations may have to be enforced in the end.

The recent decision of the District Court of Travis County in the matter of the Danciger injunction was favorable to the claims of proponents of proration. An appeal has been made to the Court of Civil Appeals, and it will probably be carried on to the Supreme Court. The moral effect, however, of the decision of the District Court will do much towards helping the general situation.

Proration of Yates Pool, Pecos County, Texas

By H. C. Hardison,* Midland, Texas

(Tulsa Meeting, October, 1930)

The Yates pool, Pecos County, Texas, has greater potential capacities than any other field in the United States. This field is notable for the large return it yields on capital invested, for low production costs and for the orderly and conservative manner in which it was developed and continues to be operated.

The proven area is 20,000 acres and there are 392 producing wells, or approximately 1 well to 50 acres. The theoretical daily potential is 5,250,000 bbl. as determined by 1-hr. open-flow gages. Individual well gages vary from a few barrels to 8500 bbl. per hour, and well depths range from 1000 to 1800 ft. The greater part of the production is from a very porous limestone, and by agreement no productive well has penetrated the lime more than 225 ft. The forces driving the oil from the formation to the surface are hydrostatic head, expanding gas or a combination of the two. The degree of effectiveness of either depends upon the structural position of, and porosity encountered in, the individual wells. Approximately 95 per cent. of the wells in the field flow naturally. The pipe line outlet of the field at the present time is 100,000 bbl. per day, which is less than 2 per cent. of the daily potential.

Difficulties and Principles of Proration

It became evident during the first year of the development of this field that operators would have to devise a scheme to allocate pipe line runs equitably among their different properties. When the idea of proration was first inaugerated, the matter of spacing wells was given consideration. This was given up through fear of legal difficulties. Storage was also a question that was given considerable thought, and a plan was finally developed which went into effect Oct. 1, 1927. It was decided that the oil runs should be prorated according to the total potential capacity of all the wells which the several operators had in the field. The potential capacity of the wells was measured by a 1-hr. open-flow gage. All runs to storage by an operator were deducted from his daily allowance.

* The California Co.

This plan stimulated drilling, because, regardless of holdings or other value, the outlet from each property depended entirely upon the potential of the wells. The only thing gained by this scheme was that the outlet was divided among all of the producers, but it did not reflect the value of the holdings and placed a premium on competitive drilling, which was poorly distributed. Each operator concentrated drilling upon what he considered his best acreage. Under this plan one small area was drilled to an extent of one well to 12½ acres. Therefore, since acreage was decidedly an element for consideration, it was decided to create a plan on an acreage basis.

The services of an independent geologist were obtained, and he outlined the proven field. All acreage within these limits was given consideration. If an operator had acreage outside of these limits which he thought to be productive, it was necessary for him to drill wells to determine this fact. This new scheme was put into effect on Jan. 1, 1928.

Difficulty arose from the fact that some companies held both good and poor acreage, while others were confined to relatively small parcels of very good acreage. A few arbitrary adjustments were made to compensate operators whose acreage all had much higher potential than the average potential of the field. These adjustments were a constant source of irritation because there was no logical basis upon which adjustments could be made.

Under this plan a fairly prolific area near the top of the structure was drilled to the extent of one well to 14 acres. The operators of this acreage had undeveloped acreage near the edge of the field but within the limits of the proven area as officially defined. Oil allowed them for this undrilled edge acreage was withdrawn from the top of the structure. These heavy withdrawals tended to cause a rapid local decline of pressure, which would set up undue drainage from neighboring acreage.

It became evident, therefore, that there were certain principles that must be guarded in a proration scheme: (1) that the potential must be the governing factor and considered on an acreage basis; (2) in order that the acreage drilled should reflect the condition of the parcel, each type of acreage must produce its own oil.

Present Plan of Proration

In July, 1928, the present plan of proration was put into effect. Since there was an average of one well to every 100 acres, the field was divided as nearly as possible into 100-acre units. Any leases smaller than this were considered as full units except in cases where a fractional unit is contiguous to a full unit held by the same operator. In this case a split unit was considered and prorated accordingly; that is, a lease consisting of 140 acres was given credit, for proration purposes, with 1.4 units,

while a 40-acre lease was given a full unit credit. Under this plan each unit determined its own potential and produced its own oil. The thought uppermost in choosing the 100-acre unit was to devise a scheme in which the minimum amount of additional drilling would take place. The acreage factor was injected into the scheme for two reasons: (1) It was a defense to small wells because it was recognized that no well should be forced to produce below an economic limit that would permit it to remain an asset and (2) had the large wells been allowed to flow under normal conditions, the outlet would have been so enormous that it would have been physically impossible to pipe the oil away.

Under this plan 25 per cent. of the pipe line outlet was divided equally among all of the producing units in the field, and the 75 per cent. was prorated according to the average unit potential. The average unit potential is the figure obtained by adding the daily potentials of all the wells on the unit and dividing the sum by the number of wells. The daily potentials of the wells are determined by gaging each well, open flow, for 1 hr. every six months. The ratio that the average potential of each unit holds to the sum of all the unit average potentials, multiplied by 75 per cent. of the pipe line outlet, gives the potential allowance of the unit. The sum of the unit allowance and the potential allowance is the total allowance for the unit. Each unit must produce oil allocated to it, and offset wells on neighboring leases are produced ratably to their potentials. It is believed that this method distributes withdrawals equitably and prevents the uneven diminishing of pressure.

The pipe line outlet at the time this plan was adopted was approximately 3 per cent. of the daily potential of the field.

This scheme of proration was placed in effect by an order of the Railroad Commission of Texas, and is administered by an umpire appointed by that body. The Commission's order specifies an Advisory Committee consisting of one representative from each company. This committee appointed an Executive Committee from its members to work with the Umpire in administering the order.

Study of Field Problems

During the early development of the field the operators appointed a committee of company engineers to make a study of conditions and report their findings. The report placed considerable stress on gas-oil ratios and rock pressure. The latter was determined by gaging the shut-in pressure at the bottom of the hole with a pressure bomb. The average of several of these tests was 700 lb. per square inch. Casing programs were discussed and recommendations were made to adequately protect shallow fresh-water sands from contamination and also insure against loss of oil from the high-pressure lime pays to the overlying porous strata.

A study of the field problems has been continuously carried on by several of the company engineers. The Engineering Committee became active again in June, 1929, to continue studies cooperatively, and in particular to report on some method by which the potential of the wells could be determined without opening the well for a 1-hr. period.

The committee proposed such a method in a report submitted December, 1929, and recommended further study to test the method. The confirmatory tests are now in progress. A description of the method has been published[1] and a discussion of the method is being presented to this meeting.[2]

The report of the field engineers also discussed the occurrence of oil and of water at definite horizons in the lime. It was pointed out that these producing horizons have definite intervals between them, and the edge waters in four of these were mapped. The operators, recognizing that rapid withdrawal of oil in the prolific area would cause an uneven advance of edge waters and trap off large quantities of recoverable oil, have never considered raising the field outlet above 136,000 bbl. per day. Well spacing was discussed and it was recommended that sufficient wells be drilled on edge leases to insure the even encroachment of edge waters. As a result, 35 additional wells have been drilled for this purpose.

The Proration Umpire receives water reports from all companies each month, through which he keeps check on the advance of waters and recommends the necessary plugging to the operators. Such waters have been completely shut off in a number of wells. Water control is being effected on certain edge wells by restricting the flow to such an extent that clean oil is being produced.

Conservation of Gas

The study of subsurface conditions has indicated that in certain areas in the field there is a gas sand just above the lime pay. Operators have lowered casing points below this sand in order to reduce the gas-oil ratios. Others who had cemented casing above this point are now taking steps to set packers on tubing between the gas sand and the lime pay to conserve gas.

The operators, realizing the advantages of conserving formational gas, have adopted a tubing program to tube all wells having a higher gas-oil ratio than 450 cu. ft. per barrel, which was the average for the field. Results from wells tubed to date indicate that this policy has increased the gas efficiency of production, caused small wells to flow steadily through tubing, and minimized the hazards of water encroachment. A

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[1] Yates Pool Committee Proposes Proration Method Based on Rock Pressure. *Petr. Engr.* (1930).

[2] W. V. Vietti. See page 215.

report which was presented at the A. P. I. meeting Sept. 4 and 5, 1930, at Galveston, by members of the Engineering Committee, stated that "in 55 representative wells, tubing is saving 4,028,000 cu. ft. of gas per day. This is a gas saving of approximately 33 per cent. by volume, while the oil production was increasing 1057 bbl. per day."

Some experiments with bottom-hole beans have shown beneficial results in increasing the efficiency of oil flow. The tests have not progressed very far because of the difficulty of obtaining an opening of exactly the size necessary to secure the prorated amount of production.

A gasoline plant was put into operation in December, 1929, capable of handling twenty million cubic feet of gas per day. The average gasoline content of the gas is approximately 1 gal. per 1000 cu. ft. An investigation was carried on to determine the trap pressure required to obtain the largest gasoline content from the gas. It was found that reduction of the pressure of the traps from 50 lb. to atmospheric increased the gasoline content of the gas from 0.62 to 1.90 gal. per 1000 cu. ft. Most operators are taking steps to elevate traps so that the pressure can be reduced to a minimum in order to obtain the greatest possible revenue from the gas produced.

Yates Plan a Success

The data being gathered by the several company engineers are assembled and correlated in the Umpire's office by an engineer on the staff of the Umpire, who acts as chairman of the permanent Engineering Committee. The Engineering Committee enjoys the whole-hearted cooperation of the field men of all companies.

The Yates pool is the outstanding example of the benefits derived from the orderly development and operation of a field under effective proration. This is indicated by the fact that it has produced 96,500,000 bbl. in a period of three years with little apparent decline in indicated potential production. This is almost one-third as much as the total production from all of the other West Texas fields, some of which had high potentials and are now nearing a point of exhaustion because they were produced without effective cooperative control. The plan has lengthened the profitable life of this field and has resulted in the substitution of underground storage for tankage.

The perfection of this plan was the result of one year of earnest effort on the part of the operators to arrive at a formula that would express the relative productive value of the different leases and would apportion their outlet in conformity with these values. It has fostered a desire for practical conservation and a fine spirit of cooperation among the operators, which is being carried by them into other fields that are now being prorated.

DISCUSSION

(J. B. Umpleby presiding)

J. R. SUMAN,* Houston, Texas.—I happen to be chairman of the Proration Committee in the Yates Pool, and believe it is the best prorated pool in the world. We are conserving the gas and we think we will get three or four hundred million barrels of oil from it. It so happens that the group controlling this production is content to produce a small amount of oil.

E. OLIVER,† Ponca City, Okla.—I am interested in Mr. Suman's statement that this is the best prorated field in the world. Just what things must we do to bring about that result in other fields?

J. R. SUMAN.—The factor that bears on this from an engineering standpoint is that the structure has been drilled with widely and evenly spaced wells in sufficient number, so that there is an equitable withdrawal of oil over the entire field. Also, although it is a field of widely diverse ownership, there never has been any serious trouble as to the method of participation in the outlet. No other field under proration, so far as I know, has such a low gas-oil ratio. No other field has such a large unit of production (100 acres).

E. OLIVER.—Is adherence to the acreage factor responsible for success of proration in that pool? Might this be the factor that makes it easy? There seems to be a mistaken impression that the standard of production should be based on the open flow of wells. We think the man with 40 times the acreage should be entitled to 40 times the production, other matters being equal. But under the open-flow method of proration, they receive the same amount of production.

J. R. SUMAN.—We have had to defend the acreage factor on several occasions. For this reason, in arriving at the acreage allowance factor in withdrawing the oil in the structure, we tried to simulate normal withdrawal conditions. Taking a field that could produce several million barrels a day, it would probably be physically impossible for any one company to handle, say, one million barrels per day, but some company on the edge of the field with production of only ten thousand barrels could probably handle all of it, so we insert a dampening factor called the average allowance, in order to simulate percentages that would prevail under conditions of untrammeled development. Also, if participation were based on potential alone, a company with a 1000-bbl. well in the Yates pool would get only 1000/5,500,000, or 0.018 per cent. of the outlet, which in the case of 100,000 allowable production would be 18 bbl. This is manifestly insufficient.

E. OLIVER.—Then the underlying condition is that the amount to which the owner is entitled of the oil and gas in the common pool is that which was originally contained in his land, and all these other factors are merely to assist in determining that quantity.

J. R. SUMAN.—We believe that proration of oil from a common pool has to be based on something other than the potential. There must be something to bring the withdrawal rate up to what it would be under untrammeled conditions. I want to state positively that the ultimate aim of proration and of unit operation should be to recover for each leaseholder only that oil which originally underlay his property. In other words, proration and unit operation do away forever with legalized piracy, which says that oil belongs to the man who reduces it to possession.

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† Earl Oliver & Co.

Unit Operation in California, with Discussion of Kettleman North Dome Association*

By Joseph Jensen,† Los Angeles, Calif.

(New York Meeting, February, 1931)

California's outstanding contribution to unit operation is the plan of development now established for the North dome of the Kettleman Hills. Beginning April 1, 1931, the Kettleman North Dome Assn. will control the unified operation and development of 10,800 acres of proven and semiproven oil land, and at the same time the Standard Oil Co. of California will operate as another unit its fee land of 9460 acres of similar character. The holdings of the two companies are in a checkerboard mile-square pattern. In addition to this, 410 acres of land may yet be included in the Kettleman North Dome Assn. unit and 530 acres of land are definitely out of both units. The owners of some of this land have expressed their intention of cooperating in a reasonable way with these two units. Cooperative agreements are now in force as to most of this field.

Under the definitions of a unit pool and a near-unit pool,[1] the operation at Kettleman Hills will be a near-unit operation, but because of the size of the structure and its proven highly productive character, the arrangement concluded on Jan. 31, 1931, in the approval of the Kettleman North Dome Assn. Agreement by Secretary of the Interior Ray Lyman Wilbur and by California State Oil and Gas Supervisor R. D. Bush is of outstanding importance to the entire oil industry.

No other major unit operation plans are under way in California at the present time. There has been some little discussion of a plan in the North Belridge field and a feeling that the discovery of oil in the Lost Hills field and also in the South Belridge field would necessitate consideration of unit plans. So few data are available for these areas, as to the land that should be included in such unit plans, that little constructive action is now possible. The beginning of drilling on the Middle dome of the Kettleman Hills also makes it an area deserving consideration for unit operation. All four of the above-named areas lie on the west side of the San Joaquin Valley, in Kings and Kern counties, to the south of the

* Published by permission of J. H. Jenkins, General Manager of the Production Division, Associated Oil Co., San Francisco, Calif.

† Chief Petroleum Engineer, Associated Oil Co.

[1] J. Jensen: Unit Operation in California. *Trans.* A. I. M. E., Petr. Dev. and Tech. (1930) 71.

North dome of the Kettleman Hills. The North Belridge, South Belridge and Lost Hills fields are already sources of production of heavy oil, and a well-defined structure exists in the Middle dome of the Kettleman Hills. The prolific Temblor formation of the North dome will be the source of deep oil if discovered in South Belridge, Lost Hills and the Middle dome of the Kettleman Hills, while already it is the source of production of one well in the North Belridge field. Because of the uncertainty as to future developments in the four last-named areas, nothing more can be said at this time. The remainder of this discussion will be devoted to the Kettleman Hills North dome near-unit development.

North Dome, Kettleman Hills

The North dome of the Kettleman Hills is a clearly defined anticline, almost perfect in its surface exposures for geological textbook demonstration. It was long regarded as a possible source of oil and was withdrawn as early as 1909 by President Taft from oil development, upon the recommendation of Dr. Ralph Arnold, then a geologist in the U. S. Geological Survey, and Dr. George Otis Smith, Director of the Survey.

Several wildcat wells were drilled in the hills, but it remained for the Milham Exploration Co. to make the discovery of commercial production. Milham-Elliott No. 1 blew out on Oct. 5, 1928, when the hole was 7095 ft. deep, in redrilling, although the hole had been originally drilled to 7236 ft. Production from this well has declined from 4200 bbl. of 60° gravity oil to approximately 1500 bbl. This flow of oil was accompanied by enormous volumes of gas, amounting at times to as much as 89,000,000 cu. ft. per day.

Wells encounter the top of the Temblor formation, which is the source of the oil, at depths varying from 6120 to 7050 ft. The limits of the pool have not been defined by drilling. The top 1000 ft. or more of the oil zone is similar to the discovery well, so that an oil which is 90 per cent. gasoline is produced along with 25,000 to 30,000 cu. ft. of gas per barrel of oil, furnishing 34 gal. of casinghead gasoline per barrel, with the result that 1 bbl. of this light oil is equivalent as a source of gasoline to approximately 3.87 bbl. of Southern California crude. Other wells drilled deeper seemed to secure on their initial tests a darker and heavier oil, so that operators had hope that the structure would furnish a different oil without so much gas.

On Sept. 4, 1930, Superior Oil Co. Huffman No. 1 was completed at a depth of 8323 ft., with an initial production of about 10,000 bbl. of 40 gravity oil, and a penetration of 1258 ft. of the zone. The production of this well has since increased to as much as 13,595 bbl. per day and 41,929,000 cu. ft. of natural gas. The oil is 37 to 39 gravity and the gasoline content of the natural gas is 1.64 gal., thus furnishing about 5 gal.

of gasoline per barrel of oil. The oil itself contains 52 per cent. gasoline, nearly twice the percentage of Southern California crude.

On Jan. 24, 1931, Petroleum Securities Co. Felix No. 2 was completed at a depth of 8100 ft., with a penetration of 1274 ft. of the Temblor formation. Petroleum Securities Felix No. 2 is now producing at the rate of 5500 bbl. of 42 gravity oil and 5,504,000 cu. ft. of gas, with a gasoline content of 1.46 gal. Hence, as a source of gasoline, 1 bbl. of the "heavy" Kettleman Hills crude equals more than 2 bbl. of Southern California crude.

There will be no difficulty in segregating the light oil from the heavy oil, as no intervening waters occur. In the field there have already been drilled 10 wells in which perforated oil strings have been landed, and 23 wells in which the water strings have been landed, where penetration of the Temblor formation varies from 13 to 998 ft. These open-hole wells have a cement plug at the shoe of the water string and are in condition for immediate deepening to the heavier oil. They could readily be placed on production within 60 to 90 days and should be able to produce from 5000 to 10,000 bbl. per well. As they are distributed throughout the 22,000 acres of the field, each would have a large drainage area and undoubtedly would maintain a steady flow with very little decline for the next year. The eight producing wells in the field are now making 27,310 bbl. of oil per day. Twelve wells are drilling at proven locations. Under competitive development the field could easily produce 175,000 bbl. per day within the next 90 days. This would be equivalent, as a source of gasoline, to 350,000 bbl. of Southern California crude. Present production of the state is a little in excess of 525,000 bbl. per day. Such figures represent only what might happen in 90 days of competitive development work. What might happen after a year or two of competitive development work may well be imagined.

Regulation by Kettleman North Dome Association

Until the heavier oil was discovered, it was felt that the California gas law furnished a means of regulating the production of this field by limiting the production of the natural gas to market outlets. With the development of a gas-oil ratio of as little as 1000 cu. ft. of gas per barrel of oil in Petroleum Securities Felix No. 2, and an assured gas outlet of from 100,000,000 to more than 150,000,000 cu. ft. of gas, it is obvious that the Kettleman Hills would not be sufficiently regulated by the operation of the gas law, and that it could have become a serious menace to the oil industry of the state and the country unless a method of regulation for its development had been worked out successfully. Except for the danger spots surrounding the fee lands which are not controlled either by the Association or by the Standard Oil Co., the Kettleman Hills situa-

tion may be regarded as having been brought in hand by the formation of the Kettleman North Dome Assn. Intelligent, rational development of this field may now be expected at a minimum of expense and a maximum of recovery, in so far, at least, as the lands of the Association and the Standard Oil Co. are concerned.

Producing and drilling wells in the Kettleman Hills and the limits of the area containing the checkerboard acreage of the Standard Oil Co. and the Kettleman North Dome Assn. are shown in Fig. 1. On this map are shown two heavy lines, an outer or so-called "blue" line and an inner or so-called "red" line. The N.E.¼ and the S.W.¼ of sec. 29, T.21S., R.17E. and land in the W.½ of sec. 35 and all of sec. 36 embrace the land that either will not be or may not be included in the Kettleman North Dome Association.

Land within the blue (outer) line is divided as follows:

	Acres	Acres
Standard Oil Co. fee land		9,460
Association land		
Government leases	9,640	
Fee lands—leases between and lands owned by oil companies	1,160	
		10,800
Total land in two units		20,260
Fee lands of operators willing to enter Association but lacking lessors' consent		410
Fee land leases not signed up to join Association		530
Total		21,200

Considering the fact that the limits of the field are still unknown while its central portion is definitely proven productive oil land on a well-defined structure, and the divergence of interests that such a situation made in establishing the outer limits of the area to be embraced in the unit and in setting up a basis of participation, the formation of the Kettleman North Dome Assn. represents an important development in unit operation, as well as evidence of a willingness to cooperate upon the part of the operating oil companies, the Federal Government and the oil companies owning fee land.

Some of these companies have placed practically all of their resources in California in the Association. Consequently, they have naturally regarded with fear the possibility that since the Kettleman Hills could be so well controlled, if it became a near-unit operation its production would be regulated to the advantage of other producing areas in the state. In this regard they had considerable justification for a doubting attitude, because many of the wells capable of producing in the field had already been completely shut in for more than a year on account of the agreement of July 25, 1929, between Secretary Wilbur and the holders of Government

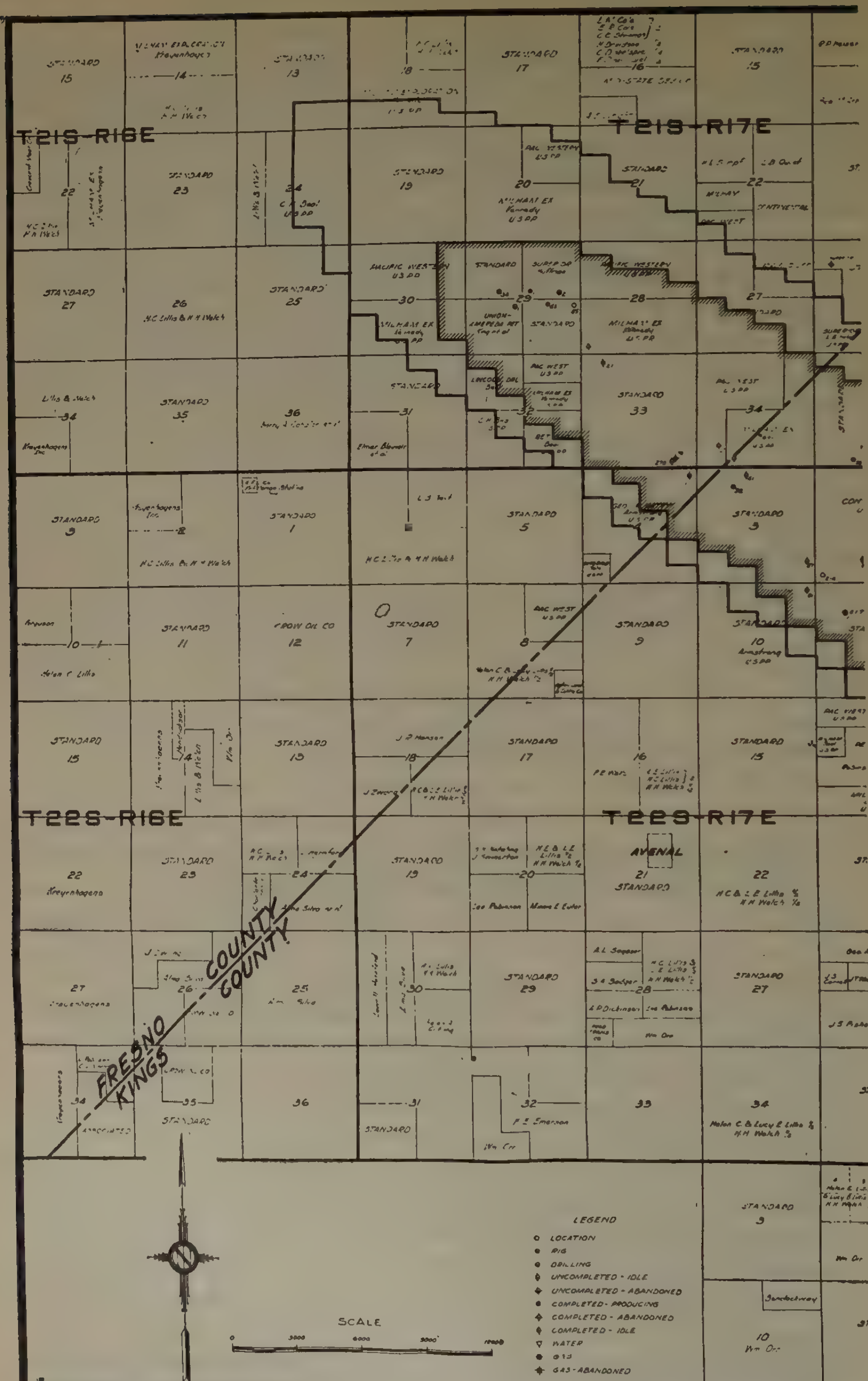
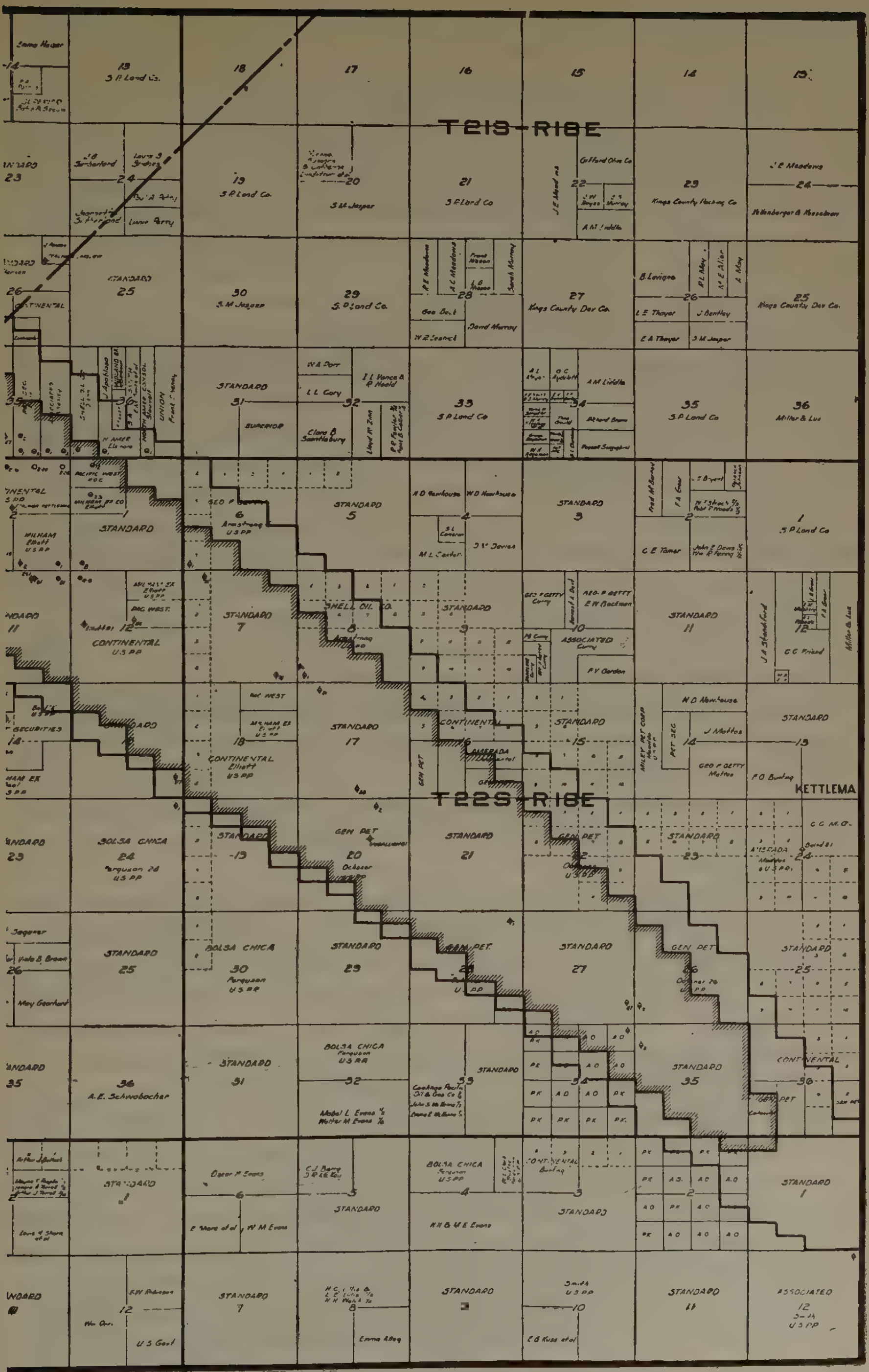


FIG. 1.—KETTLEMAN HILLS NORTH DOME, FRESNO AND KINGS COUNTIES,



CALIFORNIA. Outer line is the blue line; inner line is the red line.

permits. Such agreement was workable only because of the cooperation of the Standard Oil Co., which regulated its corresponding offset wells in harmony with the spirit of that agreement.

In lieu of a production test to demonstrate the discovery necessary to validate the Government leases, the agreement of July 25, 1929 provided that the wells should be deemed completed when a water shut-off was secured and the Temblor zone encountered. As compensation for those wells thus shut down, the agreement of July 25, 1929 provided that the four producing wells of the "discovery group" should contribute from 10 to 25 per cent. of their production to the owners of all wells in the North dome area completed in the manner provided in the agreement, on the basis of an equal portion of such percentage to each of said completed wells, exclusive of the four wells making the contribution: *viz.*, the discovery well, Continental Oil Co. No. 12-8 and Standard wells No. 1P-8 and No. 11P-81. The first of such payments was made for the month of November, 1929, on the basis of 10 per cent. of the production of these four wells. Later on the contribution was increased to 25 per cent., but even so, the distribution to the wells that were shut down decreased rapidly on account of the number of wells thus completed. At the present time there are 25 wells participating in such distribution.

Even more stringent in its requirements was the provision of the agreement that practically all other drilling activities except those necessary to establish discovery should be suspended until after July 31, 1931. Operators on Government lands entered into this agreement of July 25, 1929 "in line with the Government's policy of oil conservation" and "for the purpose of contributing" to that end perhaps more than for the purpose of curtailing the production of the field.

This agreement of July 25, 1929 has served a most admirable purpose in keeping the greater part of the field in a state of suspended operation while the plan of the Kettleman North Dome Assn. was developed and until it is put into effect. Dr. George Otis Smith, as the personal representative of Secretary Wilbur, negotiated this agreement with patience and great tact during the spring and summer of 1929.

One of the provisions of the agreement required that the parties interested in the Kettleman Hills field should undertake "to consider a plan of unit development or other cooperative method of developing this great structure with a maximum production and utilization and a minimum of operating cost," and in turn, the Secretary agreed to "propose the necessary legislation enabling the Government's participation in the proposed cooperative plan by authorizing both the necessary acreage involved and the substitution of a fixed and definite share in the output in lieu of the existing different rates of royalty for primary and secondary leases."

Beginning on Dec. 11, 1929, meetings were held to comply with the requirements of the agreement. As a result of the first few meetings, one could hardly feel that any particular forward steps were being made. Nevertheless, engineering committees were appointed to prepare plans on unit operations and plans for cooperative development. These reports were submitted in January of 1930 and Secretary Wilbur met with the Kettleman Hills operators in the latter part of that month.

Kettleman North Dome Committee

On Feb. 12, to further advance the work, the operating companies in the field organized the Kettleman North Dome Committee, with William Reinhardt of the Shell Oil Co. as chairman. To him much credit is due for his patience and persistence in advancing the work of the committee to its final conclusion, for at many times almost insurmountable problems developed.

Before the reports of the engineering committees were submitted there was no outstanding advocate for unit operation, but there were several advocates for a cooperative development plan, since that was recognized as being essential. Operating companies were requested to file briefs or comments on the two plans, indicating their suggestions for needed changes to meet their viewpoint and their individual situations.

On April 30 Dr. Smith met with the Committee to discuss the legislation necessary to accomplish the purposes of a plan of unit operation, for by that time sentiment in favor of unit operation had crystallized to such an extent that the idea of cooperative development was advocated less strongly. At this conference it developed that the Leasing Act should be changed in four ways; *viz.*,

1. To permit cooperation within a single pool so that an operator could have an interest in more than 2560 acres of land.
2. Modify the royalty on the "B" leases so that they should be fixed amounts and not dependent upon time or rate of drilling or location of wells.
3. Modify drilling requirements so as to permit unit operation drilling rather than lease operation drilling.
4. Extend the term of the Government lease beyond 20 years to the life of the unit operation agreement.

Following this, matters did not move forward very rapidly during the months of May and June. Some of the companies delayed filing briefs discussing the proposed unit plan. As late as May 27 it appeared that the companies that had no wells seemed to favor unit operation, while the companies that had wells still seemed to favor controlled development work.

Standard Oil Co. Agreement with Association

On June 27 the Standard Oil Co. presented its objections to a single plan of unit operation. It was confronted with a difficult problem, since nearly one-half of its oil reserves in California were in the Kettleman Hills. In any single unit, its percentage of interest would be much greater than that of any other company. On the one hand, it might be charged with controlling the organization, or on the other it must conduct itself as a trustee for every other acre of oil land in the field. The Standard therefore proposed that all of the other operators form a unit; that the Standard fee land be treated as another unit, and that the operations of the two units be regulated by agreement. This is the general plan that has been followed. The Standard Oil Co. also has 200 acres of Government land under lease inside the blue line, which became a part of the Kettleman North Dome Assn. acreage. Because of the understanding that developed in forming the Kettleman North Dome Assn. with the help and cooperation of Standard representatives, it is clear that no difficulty will arise in working out the details of the agreement for the operation of the two units.

Government Cooperation

Congress passed an amendment to the Leasing Bill which was approved July 3, 1930, making possible the changes necessary to permit the formation of a unit containing Government land.

On July 30, Secretary Wilbur and Dr. Smith met with the Kettleman operators. Dr. Smith again came to California during October. Upon his appointment to the Power Commission, Secretary Wilbur was represented by G. W. Holland, who spent a good part of December and January in California. Meetings of the Kettleman North Dome Committee were held frequently from August to November and almost daily during December and January.

The final procedure adopted was to incorporate the Kettleman North Dome Assn. and draft its by-laws, including in these two instruments no controversial matters. This permitted such organization work to proceed during December without further delay. All controversial matters and operating problems were then summed up into an agreement to be signed by the Association and all of its operator members.

The most important problems requiring solution were those relative to participation and the rate of production of the unit. As an incentive to encourage limited production, the royalty scale on the Government "B" leases was increased with the rate of production, so that a high rate of production would be worth while only when there was a real demand for production from the field. The articles of the agreement bearing

upon these points are explained to show the manner in which these three problems were met.

Article III of the Agreement provides for the pro rata of contribution to call for payments to support the Association and for the distribution of oil, gas, natural gasoline and other products. It refers to a map, from which the map of Fig. 1 was made, describing the inner line as the "red" line and the outer as the "blue" line.

The red line is intended to approximate the contour line 6500 ft. below sea level on top of the Temblor formation. The area within it is never to be reduced, but should subsequent drilling demonstrate that this line does not approximate the 6500-ft. contour line, it may be expanded so that it will approximately follow that contour line. The blue line is intended ultimately to approximate the productive limits of the field and at all times to define the maximum area of participating acreage. The Association must diligently determine the correct position of the blue line. During the first five years after the effective date of the agreement the blue line, as drawn on the map, shall not be contracted but may be expanded at any time, and the participation of acreage lying between the red and the blue line may be modified. At the end of the fifth year and up to and including the end of the tenth year, the blue line is to be relocated so as to exclude lands determined to be nonproductive. However, the blue can never be drawn inside the red line nor the 6500-ft. contour line.

Each member shall participate in contributions to costs and distributions of products in the proportion that the acreage he holds within the blue line bears to the total acreage controlled by the Association within the blue line.

At the end of each year during the first 10 years the land lying outside of the red line and within the blue line shall be classified in order to determine nonproductive acreage. Thereafter such nonproductive acreage will participate during the first five years, as follows: During the first year, 100 per cent.; during the second and third years, 50 per cent.; during the fourth and fifth years, 25 per cent. From the sixth to the tenth years land between the red and blue lines is to be classified to determine land which is noncommercially productive and, after such classification, the land shall participate to the extent of 50 per cent. Except for these modifications, all land participates on an equal acreage basis, assuming that each section represents 640 acres.

Any member holding nonparticipating acreage—that is, land outside of the "blue" or outer line—may drill this land at any time and if the land proves productive, it shall thereupon be included as participating acreage and treated thereafter as other lands within the blue line, and the Association shall pay the member twice the member's cost of proving it. None of these changes with regard to land classification are to be

made except upon a two-thirds vote of eleven directors. Eight of the eleven directors will always be controlled by four or five members. Divergent interests of members are protected by Article III. Those having land between the red and blue lines enjoy participation for the first five-year period, even though classified as nonproductive. Protection of the acreage within the red line against long-continued inclusion of nonproductive lands inside the blue line is afforded by the requirement that the Association shall diligently determine the true position of the productive limits of the field.

The provision relative to royalty on the Government "B" leases in Article XIV now provides that "computation of royalty accruing to the United States, irrespective of the number of wells on the leasehold and the production therefrom, shall be based on a portion of production allocated to such lease in conformity with the principle for participation of members, provided that the royalty rate for oil for each lease not at 5 per cent. shall be computed on the average daily gross oil production for each month of the Association's acreage as follows:

Amount per Day	Per Cent.
Up to 15,000 bbl.	12½
Over 15,000 and not over 30,000 bbl.	16⅔
Over 30,000 and not over 60,000 bbl.	20
Over 60,000 and not over 110,000 bbl.	25
Over 110,000 bbl.	33⅓

This schedule is based upon 11,740 acres being included in the Kettleman North Dome Assn. Actually 10,800 acres have been signed up unconditionally, so that the rates of production given above will be adjusted in the proportion of 10,800 to 11,740, or 92 per cent. of those given above. Royalty on gas, gasoline and all other substances is to be computed as provided in the standard lease form of the Interior Department.

The Secretary of the Interior has certified that all leases of Government lands in the Association shall continue beyond the 20 years specified in the lease and until the termination of the plan, and that each and every lease is modified as to drilling and production requirements so as to conform to and be satisfied by the requirements of the agreement.

Approval of the State Oil and Gas Supervisor was made possible under the California gas law. The recent affirmation of the constitutionality of this Act by the Supreme Court of the State of California came opportunely in December of 1930.

Article IX of the Agreement was the last one adopted. It deals with the rate of production of the field. This is of great importance to the oil industry of the entire United States and is quoted in full:

"The development and producing operations of the Association shall be conducted to obtain the maximum ultimate yield of petroleum prod-

ucts from its properties without wastage of gas prohibited by the laws of the State of California and of the United States of America. The Association shall drill and produce such wells as are necessary to yield its required production from the lowest gas-oil ratio zone of the producing horizon consistent with best known engineering practice.

"As soon as it is possible to do so without unlawful waste of gas, the Association shall produce its acreage percentage of 50,000 bbl. of crude daily as the minimum output of the Kettleman Hills North Dome with any adjustments upward that the directors consider proper to protect the Association's lands from drainage. This basis of production shall be maintained until the end of the year 1931 and shall be thereafter the minimum which may never be reduced except by unanimous consent of the directors.

"After 1931 the directors of the Association shall have the direct obligation to all the members of the Association to increase the production at a reasonable rate of increase to a daily figure which, yielding at all times the maximum revenue to the members, shall be as nearly as possible a percentage of the crude oil production of the State of California equal to the percentage of the crude oil reserves of the State contained in the lands controlled by the Association."

The Association does not take over the lands under lease in the Kettleman Hills but is merely granted exclusive possession and operating rights thereon. It will buy from the various members the wells that have already been drilled by them. Much remains to be done before it will be able to take physical possession of these wells and carry on its operations in the field. This can probably be done by April 1, 1931. It is anticipated that at that time the Secretary of the Interior will terminate the agreement of July 25, 1929, whereby some 25 wells are now suspended. By deepening some of these wells, the Association will be able to develop the production required under Article IX of the Agreement.

Through this new plan, almost immeasurably valuable oil land is being surrendered to the control of the Association by 15 oil companies in the state of California, hence much thought has been given and much effort put forth by those interested in insuring its success. Not only they but the entire oil industry of the state hope that this new departure in oil-field development may prove wholly successful and satisfactory in accomplishing the purposes for which the Kettleman North Dome Assn. was created.

Economic Aspects of Unit Operation of Oil Pools

By Joseph E. Pogue,* New York, N. Y.

(Tulsa Meeting, October, 1930)

There are two methods employed in the development of oil pools. The older and dominant method is one in which the primary object is the protection of the underground deposit from drainage through competing wells, and considerations of efficiency of extraction and cost of production are subordinated thereto. The newer and less prevalent method is one in which maximum efficiency and minimum cost are the first objectives and developments to these ends may proceed undisturbed by the exigencies of competitive drainage.

The second method has developed mainly in pools under single ownership and the term "unit operation" has come to be applied to this procedure. A single ownership, however, is not essential to the method, for unity of operation may be achieved by agreement under split ownership, or even by a concert of enlightened purpose. There are examples of unit operation where neither the ownership nor the management is a unit, but merely where unity of procedure has been attained, as in the Yates pool. Throughout this paper "unit operation" is used in its broad sense without implying sole ownership or single management, although unit operation is more conveniently attained where these conditions are present.

It is evident, upon reflection, that the second method should yield results far superior to the first, for the work of exploitation can be conducted without extraneous considerations and the natural forces present in the oil reservoir can be utilized to maximum advantage. Experience has amply confirmed this conclusion and were the facts widely known and appreciated, the efforts to extend the applications of the principle of unitization would be greatly intensified.

Competitive Development of Oil Pools

It has come about that the vast majority of oil pools, or reservoirs, in the United States are subdivided by numerous surface tracts under separate ownerships. This condition arises from the prevalent practice in the oil business of acquiring prospective acreage in checkerboard spreads. Thus the discovery of oil usually reveals a mosaic of overlying ownership. Since oil is a migratory mineral and is subject to lateral

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movement where pressure is relieved by drilling, it follows that the oil originally confined within the vertical extensions of the property lines may be partly drained by operations on adjacent acreage. The law offers no protection to the underground property along its vertical boundary planes and hence the owner of the oil is forced to set up, by drilling, drainage gradients equal to those of his neighbors, or else suffer the legalized robbery of his property. In imposing upon the owner of oil property the responsibility of defending it from drainage by outsiders, the law places an intolerable burden upon the interests concerned with the efficient production of crude petroleum. The combination of subdivided ownership and an archaic law sets the tempo of crude oil production in this country and constitutes a serious obstacle to the orderly and efficient production of this commodity.

The prevalent method of producing crude petroleum has the characteristic of intensifying competition and hence of speeding up the rate of output. It results, however, in the waste of oil and gas, makes impossible the application of the best engineering practices, and leads to difficulties in adjusting the supply to market requirements. In consequence, the costs of producing oil under intrapool competition are unduly high and place the operators involved in this method at a disadvantage. During the pioneering period of the oil industry the drawbacks of competitive development within the single oil pool were overlooked, but in recent years a growing understanding of the objectionable features has become evident and now the counter method of unit operation is receiving widespread consideration.

Unit Operation

One of the earliest discussions of the economic significance of unit operation is found in a publication issued by the Smithsonian Institution in 1918[1] from which the following citation is taken:

> By some means production must be brought under the control of legitimate demand. A constructive policy . . . will encourage a type of development that will hold petroleum in the ground until it is . . . needed . . . The first step toward this end would logically be to disfavor small holdings. In the case of the public lands, this could be accomplished by appropriate legislation permitting the patent or lease of adequate acreage. In the case of private oil lands . . . a constructive policy will favor and facilitate integration, at least up to the point where each geological unit is occupied by a single producing activity . . . The elimination of excessive competition in oil production, that is to say, of competition within the geological unit or reservoir, will go far toward placing petroleum on the same footing with other mineral products . . . It will strike to the roots of wasteful production and overproduction by enabling the producer to gain greater profit in holding the oil underground until needed and then producing it according to the best current technique than by rushing headlong into hasty production as is necessary under present circum-

[1] C. G. Gilbert and J. E. Pogue: Petroleum—A Resource Interpretation. *Bull.* 102, Pt. 6, U. S. National Museum, Washington, 1918.

stances. It will create conditions of supply that will cater indifferently to inferior uses, to the sustained benefit of all activities actually dependent upon the distinctive character of petroleum products. In a word, this simple expedient will prevent the migratory character of petroleum from working at severe cross-purposes, as it now does, with the best interests of the petroleum industry and the public.

During the past few years the principle of unit operation has attracted growing attention in the petroleum industry and this matter has received careful study at the hands of many individuals as well as by such organizations as the Federal Oil Conservation Board, the American Petroleum Institute and the Petroleum Division of the American Institute of Mining and Metallurgical Engineers. The contributions of Henry L. Doherty to the subject have been particularly outstanding. In the meantime the practice of unit operation has got under way until now there are many examples of unit pools in the United States, although their aggregate output is still under 10 per cent. of the total production of the country. In foreign countries, where circumstances of discovery are different, the small landholding is much less prevalent, and the yield from unit operations exceeds the competitive production almost two for one.

Present Conditions in the Industry

Because of a train of causes, including rapid advances in technology, unsound economic policies as to price and inventory accumulation, and intrapool competition, the supply of crude petroleum has been stimulated far beyond the requirements of the market and the economic expedient of proration has developed to withhold the drilled-up supply from surface storage. In consequence a vast "potential" of crude petroleum has banked up, only a turn-of-the-valve removed from the market, while drilling still continues. The presence of this large potential constitutes the most striking aspect of the current petroleum situation and creates a new and unsolved problem for the petroleum industry. The mere presence of a large potential is evidence that the cost of producing petroleum is too high, for expenditures on drilling and other aspects of production are greater than needed to balance supply and demand. The economic effect of the potential is to raise the cost of production, to reduce the rate of return on the capital employed, and to create low prices for the commodity. The existence of a large potential, furthermore, reacts unfavorably upon the refining and marketing departments of the industry, for this poorly controlled surplus at the source of the raw material operates to create an excess expansion in refining and distributing facilities.[2]

[2] It should be pointed out that there are two types of potential: (*a*) the potential resulting from excessive drilling in competitive holdings, and (*b*) the potential caused by the procedure of flowing wells under back-pressure to gain a more efficient operation. The former is uneconomic; the latter may be present in a well-conducted unit operation.

These conditions are undesirable and harmful to the progress of the industry. The remedy for them is difficult under present practices, but the avenues toward improvement are clearly marked. To bring the production of crude oil to a sound basis will require the elimination of the potential, or at least the uneconomic portion of the potential; a radical reduction in production costs, and the exclusion of methods that create waste, either of oil or gas. These three desiderata are closely related and it requires no extended discussion to indicate that unit operation of oil pools offers the most promising means for bringing about these improvements. Conversely, these maladjustments are creating economic forces which will slowly work to favor the corrective changes.

The industry has long considered the advisability of building up an adequate crude-oil reserve as a stabilizing factor in the business. Of late years the advances in the technique of search have led to a marked acceleration of discovery and consequently to the creation of a sizable reserve. But because of competitive drilling requirements, this reserve has taken on the nature of a drilled-up potential instead of a true reserve, and therefore is proving disserviceable. The proper objective would be a *reserve without a potential.* The elimination of the potential with its whole train of unfavorable influences can scarcely be accomplished without a new method of production that will permit discovery without involving the immediate necessity of overdrilling.

Only under conditions of monopoly or of shortage can considerations of cost be ignored. It is well known that the costs of producing crude petroleum vary over a wide range according to depth, location, type of deposit, and so on. It is not so generally appreciated, however, that the method of production followed is even more important than the physical features. It is not a coincidence that the lowest-cost oil in the world (*i. e.*, Persia, Venezuela, Yates) comes from fields in which unit operation is practiced. Under conditions of oversupply, the matter of costs becomes of paramount importance, for a falling price level leaves high-cost producers floundering in red ink. Conditions now prevailing in the United States are bound to emphasize the importance of production costs and to favor all means that will lead to their reduction. A shift in demand is going on in the direction of low-cost sources of supply and this adjustment cannot be successfully combated by artificial barriers, but only by a lowering of costs on the part of the high-cost areas. As an example, the Oklahoma City pool, a high-cost field with costs accentuated by its method of development, cannot hope to compete with the Yates pool, a low-cost field with costs additionally lowered by an intelligent plan of exploitation. When we speak of competition from cheap foreign oil we should have in mind the superior production methods employed in most foreign fields, for with proper operating procedure

in this country American oil could meet competition on an equal plane wherever the transportation differential was not adverse.

A third consideration, involving the public interest, is the waste of oil and gas incidental to competitive development of oil pools. This is a matter that touches the responsibilities of both our state and federal governments, and the activities of the Federal Oil Conservation Board, the Oklahoma Corporation Commission, and the Texas Railroad Commission, not to mention the passage of the Texas Pipe Line Law and the California Gas Law, should be sufficient evidence that these responsibilities will not be treated lightly.

Prospective Course of Unit Operation

Unitization, like any other method of accomplishment, is an evolution. Whether this method will eventually entirely supersede "competization" in this country, or how rapidly it will progress, are doubtless questions that cannot be answered now. There are a number of factors, however, that appear to be accelerating the application of unit operation and there seems to be no early prospect of any change in the incidence of these forces. These factors are five in number: (1) The effect of differential cost, (2) the consequence of differential extraction, (3) the resultant of large-scale operations, (4) the need for a rationalization of supply, and (5) the matter of the public interest.

The lowered costs arising from unitization as compared with competitive development places a substantial economic advantage in favor of the newer method. As time goes on, competitive pools will find it increasingly difficult to contend with unitized pools. Already this rivalry is being actively felt in respect to low-cost foreign sources of supply, and the United States will find it difficult to maintain its place in foreign markets without unitization. In this country, the same struggle is going on between the two methods, though as yet in a less conspicuous degree, and the reason that Oklahoma is forced to consider successive reductions in the state's allowable production is to be traced, in part, to this consideration.

Competitive pools are being developed and depleted more rapidly than unitized pools, and this process shows no signs of abating. Projected to its logical conclusion, this tendency will ultimately result in a dominance of unit operation.

Large-scale activities in the oil industry tend to make for a type of exploration that results in spacious landholdings, and this tendency is accentuated by the newer methods of prospecting. The drift toward combination and merger, conspicuously in evidence in the petroleum industry, will further this propensity. It may be expected that an increasing proportion of our future pools will be reduced to ownership in unitized blocks.

The growing attention paid to the necessity of rationalizing the supply of crude petroleum is forcing attention to all means whereby this may be accomplished. As a result, the influence of constructive thought in the industry will facilitate the spread of unitization.

Finally, the accomplishments of unit operation, both in practice and in theory, appear to fit so closely the public interest as expressed by the policy of the Government through the Federal Oil Conservation Board and state commissions, that a strong influence in favor of the efficient method is set up in the field of public policy.

Forces Retarding Unit Operation

The trend toward unit operation is opposed by the forces of inertia, as exemplified by the small producing interest, the traditional practices in the industry, and the laws surrounding the exploitation of oil and gas. Of these, the most inflexible is the legal factor. The irrationality of the law of oil and gas is now coming to be generally recognized but there is no concert of opinion as to how this law may be changed. In fact, there is probably as yet no approach to unanimity of opinion that it should be changed. Yet the law of oil and gas, which in effect legalizes robbery, is manifestly so illogical, so unsound, and so opposed to the common law as related to other property rights that there is justification for believing that it is unconstitutional and would be so interpreted if brought to an enlightened test before the United States Supreme Court.

Conclusions

1. Unit operation is developing as a superior economic method of producing crude petroleum.

2. Unit operation offers the means for reducing costs, eliminating waste and gaining the economic advantage of a *reserve without a potential.*

3. The progress of unitization is being facilitated by the principle of differential cost, the principle of differential extraction, the drift toward large-scale operations, the need for rationalization of supply and the public interest in conservation.

4. Progress in unitization is opposed by custom and the archaic law of oil and gas, which may be subject to change.

5. Unitization offers the most promising means available for placing the production of crude petroleum on a sound economic basis.

An Economic Comparison of Developments in the South Field Oil-producing Region of Mexico

By Oliver B. Knight,* Tampico, Mexico

(Tulsa Meeting, October, 1930)

The producing formation in the South Field, or "Golden Lane" structure of Mexico, is a buried ridge of reef limestone of Comanchean age overlain unconformably with sediments of Upper Cretaceous, Eocene and Oligocene. The structure extends in a long sweeping arc, with the convex side toward the west, from San Geronimo, Vera Cruz, to San Isidro, south of the Tuxpam River, which it crosses at the town of Alamo. It is 52 miles long and averages ¾ mile in width.

The surface of the producing formation of El Abra limestone consists of a series of minor parallel highs which are separated longitudinally by synclinal troughs and laterally by structural saddles. The presence of these highs has been of utmost importance in the development of the field, especially in recent years when the salt-water level has risen above the synclines and confined the oil to the isolated highs. In many cases, faulty information and interpretation of the subsurface has resulted in drilling costly dry holes and salt-water wells.

Development

The development of the Golden Lane was started by the Mexican Eagle Oil Co. in 1906. San Diego No. 3, usually known as Dos Bocas, the first producing well on the structure, was completed on July 4, 1908. This well came in unexpectedly for an estimated daily production of 129,000 bbl., and, as the casing was not properly set, the well flowed wild into the Tamiahua Lagoon, causing a loss of several million barrels of oil. In flowing wild the well formed a crater which covers an area of 48 acres, out of which salt water and small quantities of gas still flow. Casiano No. 2, the Huasteca Petroleum Co., which yielded 200 bbl. of oil daily, and which was completed in November, 1909, was the next producing well to be drilled on the structure. In 1910, the same company completed Casiano No. 7, with an initial production of 50,000 bbl. daily, and Casiano No. 1, which produced 200 bbl. daily. In the same year, the Mexican Eagle Oil Co. completed its Potrero del Llano wells 1, 2 and 4, with initial productions of 500, 400 and 100,000 bbl. respectively. From 1910 to the latter part of 1919, development proceeded

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slowly because of revolutionary interference and lack of a market for the oil. During this period, the Huasteca Petroleum Co. completed its Cerro Azul No. 4, with an initial production of 261,000 bbl. of oil daily. This well is unique in the history of the industry, not only because of its tremendous initial production, but also because it has produced nearly 80,000,000 bbl. of oil in a period of 13 years, and is still capable of flowing 4000 bbl. daily. In total production, it has been surpassed only by Potrero del Llano No. 4, which has produced over 95,000,000 barrels.

The demand for Mexican light crude oil in the latter part of 1919 caused a rapid development of the field, which continued in boom proportions from 1920 until the first part of 1923. Prior to the commencement of the boom, most of the larger companies had succeeded in getting control of large blocks of land along the structure either through purchase or lease. However, the portions of the area, such as Amatlan, Chinampa and Zacamixtle, that were subdivided into small lots furnished an opportunity to many independent operators to obtain an interest in the field. This gave rise to diversified ownerships of small tracts and resulted in highly competitive drilling and development during and after the boom period.

The boom period in Mexico was one of the most unusual in the history of petroleum development. The high degree of competition, the ever-increasing demand for the oil, and the semilawless condition of the country, together with difficult working conditions, made the cost of development extremely high. Contracts for wells, which under normal conditions would cost from $18,000 to $24,000, ran from $75,000 to $100,000 each; and the costs of installations, such as pipe lines, pump stations, and camps, were proportionally high. Companies that operated their own tools were able to drill wells somewhat more cheaply than the companies that dealt with contractors; but wages, material and transportation costs were so high that even these wells averaged in the neighborhood of $65,000 each during the boom time. In comparison with present-day costs, these figures appear incredible. The only explanation is that the price of the oil and the scarcity of skilled labor, together with difficult working conditions, made it possible for contractors and individuals to demand almost any price for their services.

A comparison of development costs of properties in which small lots are owned by many individuals and companies, with the development costs of larger tracts owned and operated by one company furnishes a striking illustration of the economic waste that accompanies competitive development. For the purpose of comparison, two blocks of land of equal area, located on the Golden Lane, have been selected. One of these is in the highly competitive area in Amatlan and Zacamixtle and extends from lot 148 Amatlan to the northern Toteco boundary. This competitive block is owned and operated by 32 individuals and companies.

The other block, which is owned and operated by one company, is in Tierra Blanca and Chapapote, and extends from the northern Tierra Blanca boundary to the Tuxpam River. Both blocks include the entire producing width of the Golden Lane. They are similar both as to structure and producing conditions, and therefore furnish a fair basis for comparison.

Production

Production from the structure is controlled by hydrostatic pressure, which causes the wells to flow from the time of their completion until the accessible oil has been drained and the wells invaded by salt water. It becomes necessary, from time to time, during the life of a well to partly close in the production so as to prevent the coning of salt water in the reservoir and the resulting invasion in the well. The reservoir is undoubtedly formed by an intricate network of fissures and caverns in the crystalline, fossiliferous El Abra limestone. A consideration of this feature is necessary in making a comparison of two separate areas on the structure, for the reason that porosity varies considerably in different regions. For instance, were a comparison made between Amatlan-Zacamixtle and Cerro Azul, where one well, Cerro Azul No. 4, has produced more than the entire Amatlan-Zacamixtle area, the results would not show a true relationship. The two areas to be compared were selected not only because they illustrate competitive and noncompetitive development, but also because producing conditions have proved to be very similar. The average estimated initial production per well in the competitive block amounts to 17,500 bbl. daily, while that in the noncompetitive block amounts to 19,500 bbl. The small difference can be accounted for by the fact that many of the wells in Amatlan and Zacamixtle were not favorably located as to structure and therefore were completed as small wells.

The total production from the competitive block to Jan. 1, 1930, was 89,676,846 bbl., which gives an average of 427,032 bbl. per well drilled, or an average of 786,639 bbl. per producing well. Prior to Jan. 1, 1930, the noncompetitive block produced 71,659,345 bbl., which gives an average of 796,215 bbl. per well drilled or 1,214,565 bbl. per producing well. This shows that the average production per well from the competitive block was just a little more than one-half of the average per well from the noncompetitive block.

The present daily potential from the competitive block is 6200 bbl., as compared to a potential of 19,670 bbl. from the noncompetitive block. It is estimated that a future reserve of 4,000,000 bbl. remains to be produced from the competitive block, and that a minimum of 9,000,000 bbl. remains to be produced from the present wells in the noncompetitive block. It is considered that the competitive block is

completely drilled up, while at least 15 locations remain to be drilled on the noncompetitive block. Ten of these 15 wells should be producers and it is estimated that they will produce an average of 500,000 bbl. each, giving a total undrilled reserve of 5,000,000 bbl. On this basis, the total ultimate recovery from the competitive block will be 93,676,846 bbl., or an average of 446,366 bbl. per well drilled, as compared to a total ultimate recovery of 85,659,345 bbl., or an average of 815,803 bbl. per well drilled, from the noncompetitive block.

Costs of Development

Drilling

In all, 214 wells have been drilled in the competitive block, which amounts to one well for every 16.9 acres. Of this number, 175 wells were drilled during the boom period, and 39 have been drilled under normal conditions since its close; 117 wells, or 55 per cent., were completed as producers, giving an average of one producing well for every 30.3 acres. Based on a conservative estimate, the 175 wells drilled during the boom period cost $75,000 each, or a total of $13,125,000. The 39 wells drilled since the close of the boom were drilled at an estimated average cost of $25,000 each, or a total of $975,000. Therefore the total cost of drilling in this block was $14,100,000. To this must be added the cost of plugging 117 producing wells at an average of $3000 each, or $351,000. The estimated cost of drilling and plugging 214 wells, therefore, totals $14,451,000.

In the noncompetitive block, 90 wells have been drilled, or one well to every 32 acres; 26 were drilled during the boom period and 64 thereafter. Of these wells, 59, or 66 per cent., were completed as producers, giving one producing well for every 60 acres. The wells drilled during the boom, having been drilled by company tools, averaged $65,000 each in cost, making a total of $1,690,000 for the 26 wells. The wells drilled after the boom have cost an average of $25,000 each, or $1,600,000 for 64 wells. It is estimated that an additional 15 wells will be necessary to completely develop this block. These should be drilled at a cost of $20,000 each, or a total of $300,000. Of these additional wells, 10 should be producers, which, together with 59 present producers, will give a total of 69 producing wells on the block. The cost of plugging these 69 producers, at $3000 each, will be $207,000. The total cost of drilling and plugging in the noncompetitive block, therefore, will be $3,797,000, as compared to $14,451,000 in the competitive block.

Physical Installations

As numerous physical installations of which no records were kept were made in the Amatlan-Zacamixtle block during the boom period, it is impossible to obtain an accurate total of the cost of pipe lines, tanks,

pump stations and buildings. The general lack of organization caused by existing conditions led to unnecessary duplication of equipment and installations. It is unfortunate that accurate records of such installations are not available, for it is certain that they would increase considerably the total cost of the development of this competitive area. The available records show $3,700,780 as costs of parts of the physical installations on this block. The cost of all buildings, tanks, pump stations and pipe lines in the noncompetitive block totals $964,962. Table 1 gives a summary of the comparison of development costs and production in the two areas.

TABLE 1.—*Summary of Costs*

	Competitive Block	Noncompetitive Block
Area, acres	3,550	3,550
Total production to Jan. 1, 1930, bbl	89,676,846	71,659,345
Estimated future production, bbl	4,000,000	14,000,000
Total ultimate recovery, bbl	93,676,846	85,659,345
Total number of wells	214	105
Total number of producers	117	69
Completed as producers, per cent	55	66
Average ultimate production per well, bbl	446,366	815,803
Cost of drilling[a]	$14,100,000.00	$3,590,000.00
Cost of plugging wells	$ 351,000.00	$ 207,000.00
Cost of installations	$ 3,700,780.00	$ 964,962.00
Cost per barrel ultimate recovery	$ 0.193	$ 0.059

[a] All sums in dollars, U. S. currency.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to the Pan-American Petroleum and Transport Co. and to the Huasteca Petroleum Co. for the use of their records from which the data herein presented were obtained, and for permission to publish the paper. He is particularly indebted to Mr. Carroll H. Wegemann and Mr. E. L. Estabrook for their helpful suggestions and encouragement. To Mr. J. S. Kunkel, chief engineer of the Huasteca Petroleum Co., thanks are due for furnishing valuable information on the early development of the field and on the costs of physical installations.

Effect of Proration on Decline, Potential and Ultimate Production of Oil Wells

By H. H. Power* and C. H. Pishny,† Tulsa, Okla.

(Tulsa Meeting, October, 1930)

When an oil operator becomes a party to a proration agreement he may wonder, with good cause, whether production prorated today is merely deferred until tomorrow or whether oil might be lost. Various types of evidence obtained from production records when studied quantitatively are of great assistance in arriving at definite conclusions. A study of individual examples cited in this paper leads towards some solution of the problem, particularly when they are considered in the aggregate.

Many production curves on various pay horizons were studied. A disappointingly large number of these were of contributory value, but inconclusive. However, there were enough curves of similar type from the Wilcox sand at Earlsboro, Bowlegs, Seminole City, the Cromwell horizon at Little River, and the Simpson dolomite at Valley Center, Kansas, from which reasonably definite conclusions were drawn.

Assuming that deferred production is later made up with no increase in ultimate recovery, a curve (Fig. 1) shows the normal flowing and pumping life of a composite well, constructed by the family curve method. The initial production of the well shown is 1700 bbl. daily and the allowed production is 25 per cent. On this basis the average daily allowed rate for the first month is 425 bbl., or the area *BCDE*, which is equivalent to the area *AFDG* under the normal decline curve. The potential production for the second month is 1500 bbl. and the allowed production 375 bbl. daily. By this procedure a potential curve for each succeeding month is obtained (points *A*, *H*, *I*, *J* and *K*). If the well is opened it should produce somewhere near its potential curve for a short period and then decline at a more rapid rate than the potential curve. This theoretical analysis is basic. Actual examples exhibiting all points raised by the ideal curve are rare.

Proration in the Mid-Continent area has been effected mostly by leases rather than by individual wells; hence a well may produce any

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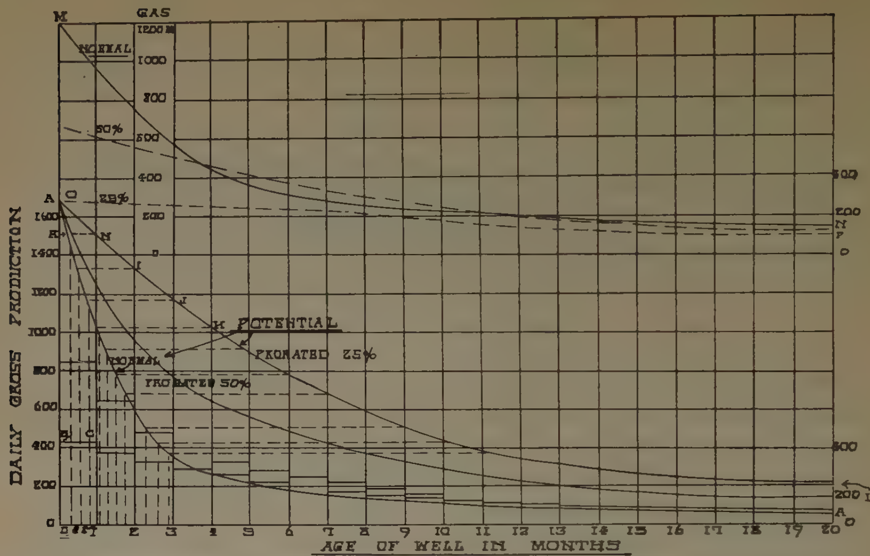

FIG. 1.—THEORETICAL CURVE SHOWING EFFECT OF PERCENTAGE PRODUCTION ON DECLINE OF POTENTIAL, CROMWELL SAND.

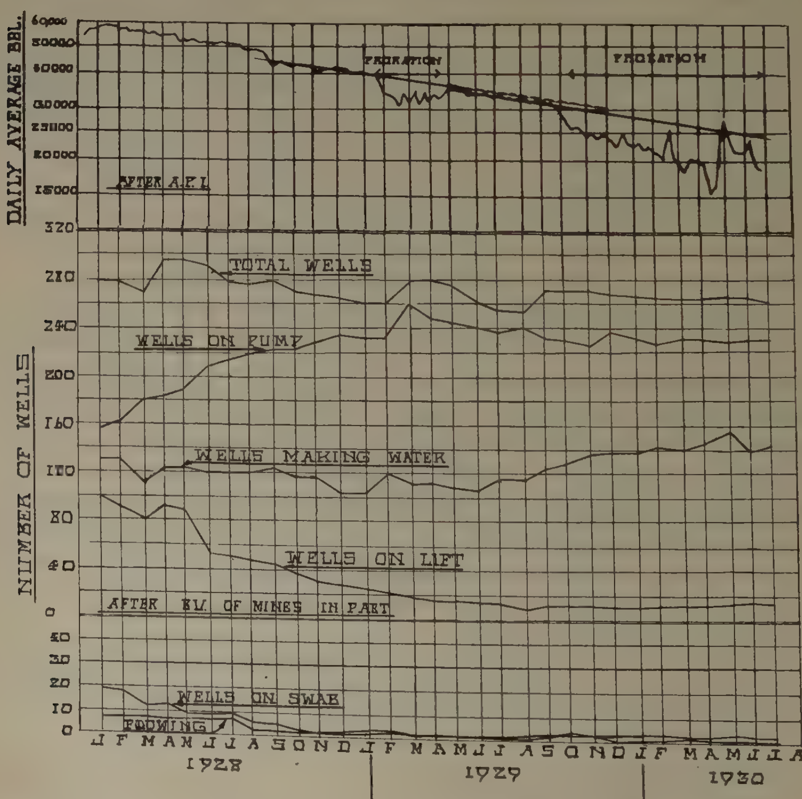

FIG. 2.—PRODUCTION AND WELL DATA, SEMINOLE CITY POOL.

proportion varying from zero to its full potential when the allowed lease production is, say, 50 per cent.

Throughout this paper the proration period from Feb. 15, 1929 to May 15, 1929 is called the first period and the proration period from Oct. 16, 1929 (Sept. 29 for the East Earlsboro district) to date (Sept. 1, 1930) is called the second period.

Fig. 2 shows the average daily oil production of the Seminole City pool and the total number of producing wells and classification of wells. From an extrapolation of production before the first proration period, it is evident that production returned to the original curve, but oil deferred during the proration period does not appear to have been made up in the first few succeeding months. However, oil deferred during the second proration period might have been made up after May, 1930, if the field had been opened to capacity, inasmuch as the potential gages taken during the last half of May show a production peak considerably above the extrapolation of the curve prior to the second proration period.

Since August, 1929, the rate of increase in number of water wells has accelerated. The questions necessarily arising from a study of the curves are: (1) Is proration responsible for the increase in wells making water? (2) Has edge-water encroachment become serious? (3) Has proration checked edge water to some extent?

It is not likely that proration is responsible for the increase in water, because the increase set in during a period of full production. It is likely, however, that in general the water problem has become increasingly serious and troublesome. If proration has retarded the water, the influence has not been great.

From a number of observations it appears that the characteristic Seminole City well increases in oil production just prior to the appearance of edge water. This is followed by a very sharp decline in oil to a relatively low, though in some cases a sustained, production. Frequently the wells are entirely watered out.

The lease decline curve (Fig. 3) shows total production of two pumping and two gas-lift wells from January to April, 1929. In April the two wells on the lift were changed over to pumping, and in May all four wells were pumped. Water appeared in September and increased rapidly through the second proration period. The peak production in July was probably the result of three factors: (1) water drive, (2) change over to pumping and (3) deferred production. This lease curve is similar to the characteristic water-drive curve for the field; the production increased, followed shortly by the appearance of water, and as the water rapidly increased the oil production dropped sharply. The encroachment of water is nearly as severe under proration as when producing to capacity.

Fig. 4 shows the production curve of a Seminole lease producing water for many months prior to the proration periods. Proration has evidently had no adverse effect on the production of this property, although water production has increased materially in July. The May

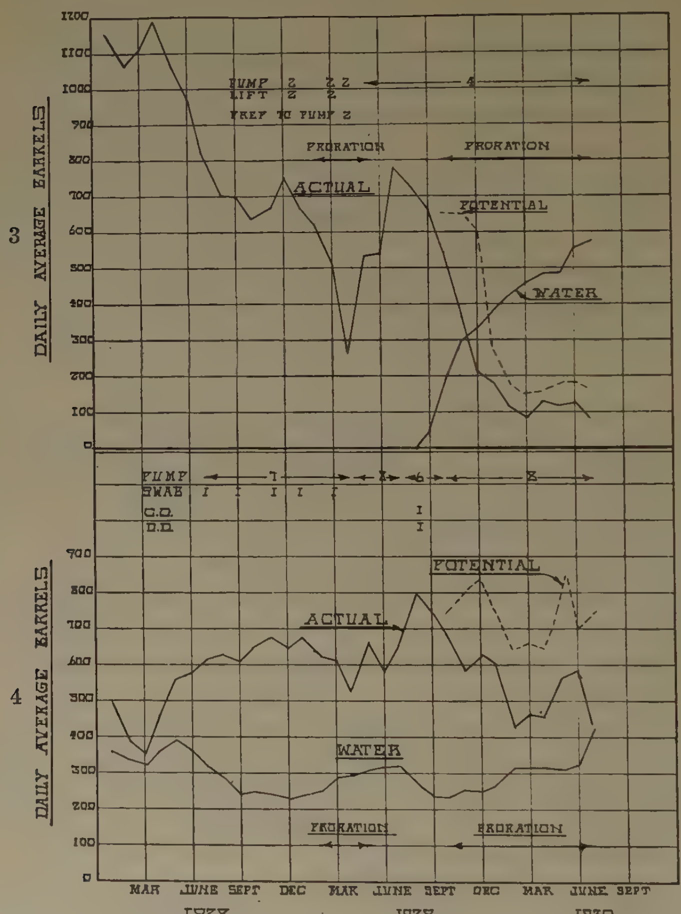

Fig. 3.—Production of a lease in Seminole City, showing increasing water during proration.

Fig. 4.—Production of a lease in Seminole City, showing sustained water conditions.

potential is 50 bbl. in excess of the previous peak, and from 200 to 300 bbl. above the extrapolation of production before the second proration.

A study of daily lease production of several Seminole City properties, for which curves are not shown, indicates that oil has been lost as a result of proration, since on the open-flow gage production did not reach the expected potential. In most cases water increased during proration.

The Bowlegs field production curve (Fig. 5) shows strong indications of deferred production being made up after the wells have been opened. The evidence is the high potential gage in May, 1930. About a year previous to the first proration the number of wells making water increased sharply as wells were taken off the lift and put on the pump, but this rate increased gradually, up to and through the two proration periods. The total number of wells fell off slightly on account of abandonments.

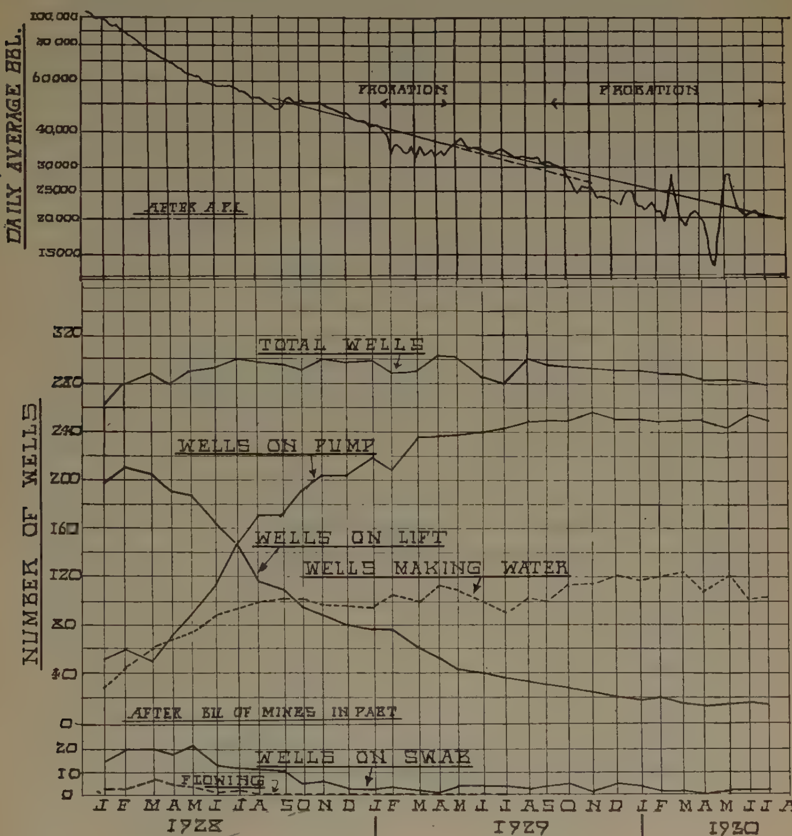

FIG. 5.—PRODUCTION AND WELL DATA, BOWLEGS POOL.

Fig. 6 is a production curve of a lease in the Bowiegs field. Two wells only pumped throughout the entire period shown. There is some indication of water drive in the sustained rate of production before the appearance of water in September, 1930. Water increased during the proration period to a peak in January, 1930, and has declined since then. The potential production increased from the beginning of the proration period to date, and an extrapolation of the curve before proration indicates that production has not been lost. Fig. 7 is another production

curve in the same pool. It shows a peak production in June, 1929, probably largely due to clean-out operations. There are two potential peaks, one in January and the other in May, 1930. Water appeared in October and as it increased the potential increased. A decline in potential and a flattening of the water curve was followed by a sharp

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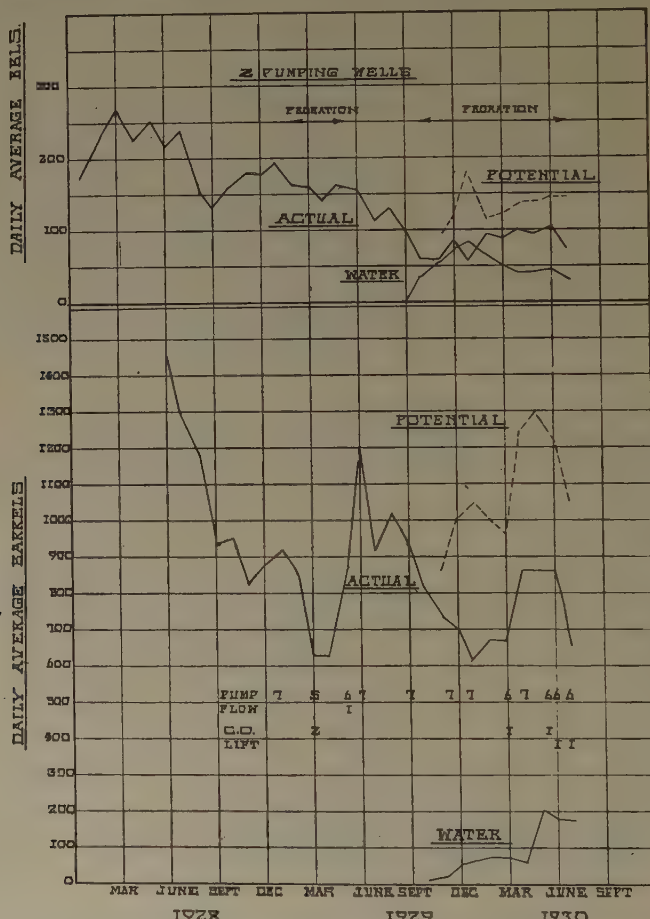

FIG. 6.—PRODUCTION AND WATER ON A LEASE IN BOWLEGS POOL.

FIG. 7.—PRODUCTION AND WATER ON A LEASE IN BOWLEGS POOL, SHOWING INCREASE IN WATER DURING PRORATION.

increase in both potential and water. The flattening of the water curve was again accompanied by a drop in potential. This is a case where natural water drive, beginning with proration, operated very much as it probably would have on full production.

The Earlsboro curve (Fig. 8) indicates that production comes back above the extrapolation of the old curve. The full 15-day gage in May,

1930, is 4500 bbl. per day higher than the extension of the portion for May to October, 1929.

Fig. 9 shows a four-well lease in Earlsboro pool, which in the early life was on lift and since November, 1929, has had three wells swabbing and one pumping.

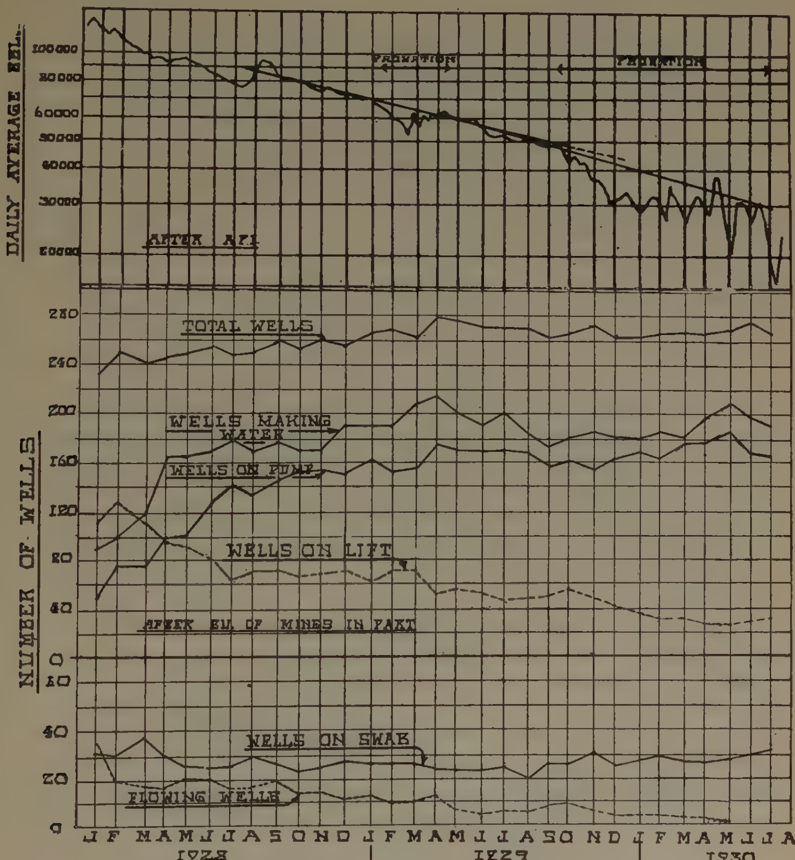

FIG. 8.—PRODUCTION AND WELL DATA, EARLSBORO POOL.

The sharp increase in water after the first proration suggests that proration has held water back. It is possible that if the wells had not been opened full after this proration period the daily rate of allowed production might have been sustained at higher levels. The curve suggests the possibility of water trapping off oil when the wells were opened to capacity. During the second proration, water production dropped to some extent when the wells were not pumped as hard as when produced at full capacity. The potential gage was well above what would have been expected on full production.

Fig. 10 is a seven-well Earlsboro lease, which for all of 1930 has had four pumping and three swabbing wells. In general the lease is characterized by a consistently declining oil curve and a slowly increasing water curve, regardless of proration periods. There is a flattening in the water curve during the first proration and a slight decline at the beginning

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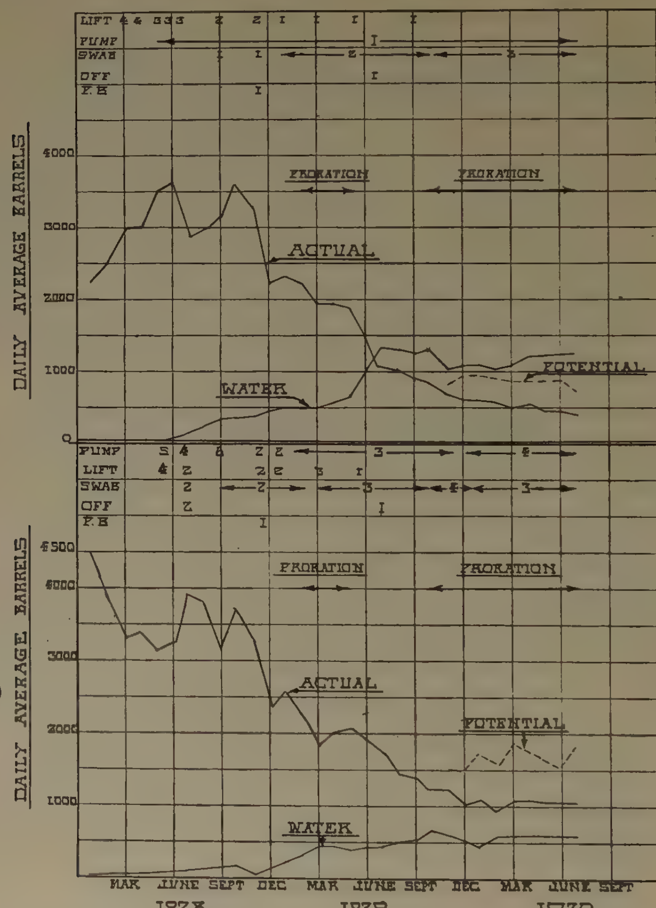

Fig. 9.—Production and water curves showing increases in water during proration.

Fig. 10.—Production and water on an Earlsboro lease, showing slowly increasing water.

of the second, but neither is definite. The potential gage in this case is well above the indicated point at which it would have been on full production. Evidently this is a case where deferred production can be secured later, and probably some additional oil.

Fig. 11 shows the decline curve of an Earlsboro well producing on the gas-lift from the Wilcox sand. It is evident that the area *BCD* repre-

senting deferred production will be made up by the increase after March, 1930 in a period of approximately three months. The well flowed between 2½-in. tubing and 6⅝-in. casing over the period shown. When the increase took place in April, 1930, the tubing had been raised, and the input volumes remained approximately the same. In July the average

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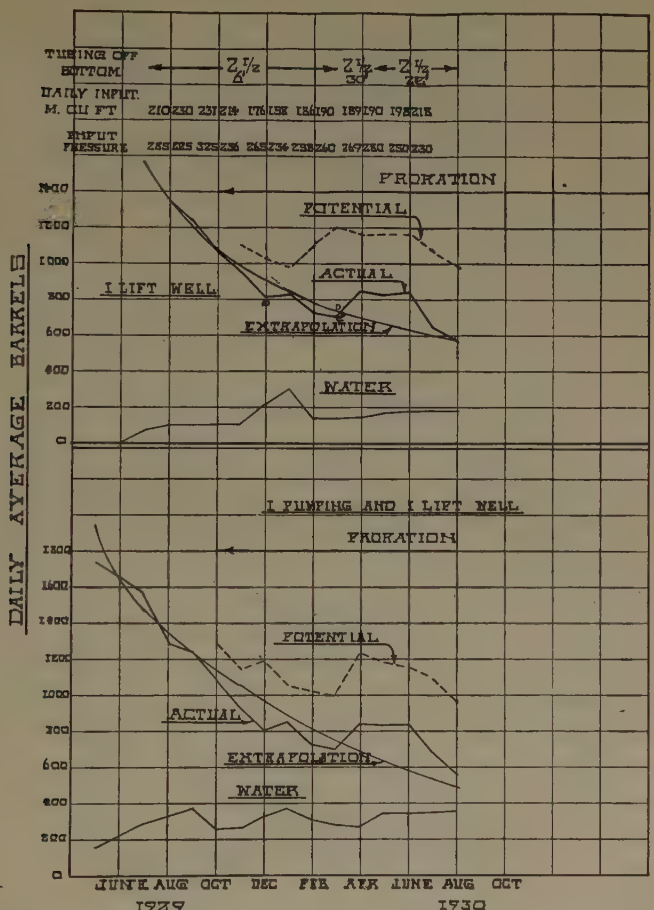

FIG. 11.—PRODUCTION OF GAS-LIFT WELL IN EARLSBORO, SHOWING OPERATING DATA.
FIG. 12.—THE LEASE CURVE OF WHICH THE WELL FIG. 11 IS A PART.

daily production dropped off to some extent, but examination of the records indicates that the production was slowed down to keep within the allowed figure. Water increased materially in December and January, but dropped approximately one-half in February and the increase since has been small. The efficiency of the water drive is thought to

have been increased by proration.

The lease decline curve, Fig. 12, shows the same general characteristics as Fig. 11. Two wells only produced from the lease, and the remaining pumping wells exhibited a more or less flattened production during proration.

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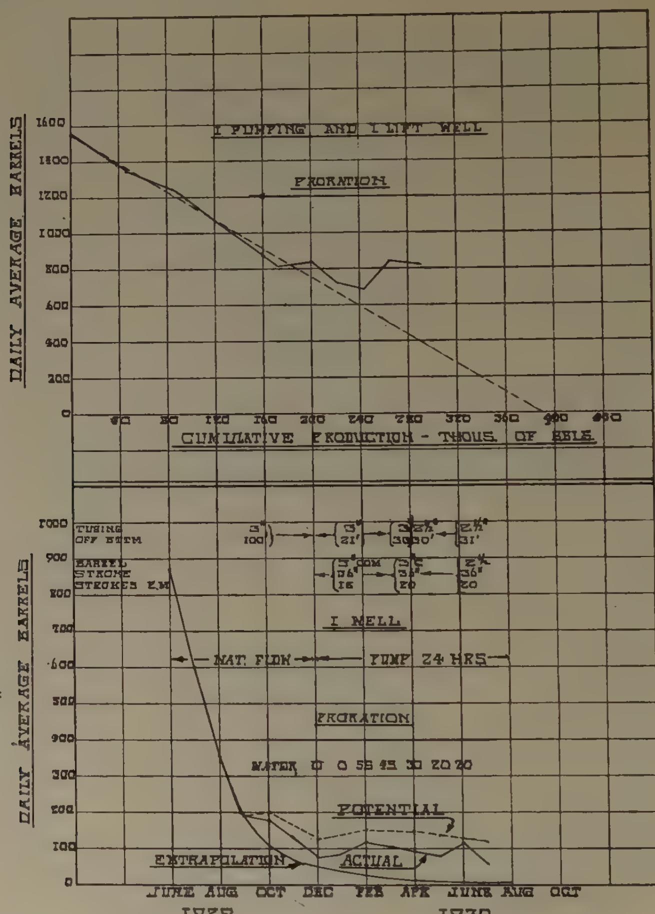

Fig. 13.—Rate cumulative curve of the lease in Fig. 12.
Fig. 14.—Production of a Cromwell sand well in Little River.

The effect on cumulative production may be noted from Fig. 13.

Fig. 14 shows the actual decline curve of a Cromwell sand well in Little River. While the well was still flowing through 3-in. tubing, proration took effect and the flowing production was maintained considerably higher than the extrapolation of prior production. When the well was put on the pump in December, 1929, potential and actual

production gradually increased for two months and then declined slightly. It will be noted from the data tabulated in connection with Fig. 14 that changes in pumping operations were relatively a minor factor in the increased production. In general, the curve indicates a better utilization of gas energy and natural water drive. It is also interesting to note that

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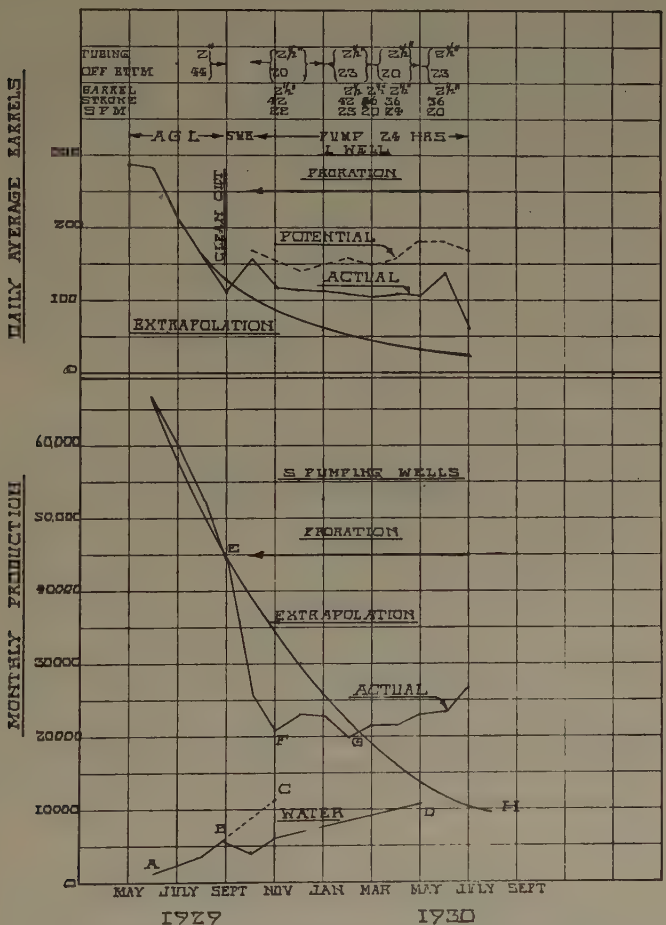

FIG. 15.—PRODUCTION OF A CROMWELL SAND WELL IN LITTLE RIVER.
FIG. 16.—PRODUCTION OF SIMPSON DOLOMITE WELLS IN KANSAS.

the amount of water declined from 55 bbl. daily in February to 20 bbl. daily four months later.

Fig. 15 is another Cromwell sand well in Little River, which shows the same general characteristics as the one in Fig. 14, with the exception of the clean-out in September, 1929, and the fact that no water has appeared in this well to date.

Fig. 16 shows the actual decline in monthly production of a five-well lease producing from the Simpson dolomite in Kansas. The extrapolation of unprorated production from June to September, 1929 results in the curve *EGH*. The graph of actual production under proration is the line *EFG* and the area *EFG* represents deferred oil which it is presumed will be made up over a period beginning with February, 1930, where the actual production curve crosses the extrapolation curve. Prior to proration. water production increased from *A* to *B* and might have increased at a corresponding rate, say to point *C*, had production not been restricted. However, with proration a more gradual rate of water increase took place, as evidenced by line *BD*.

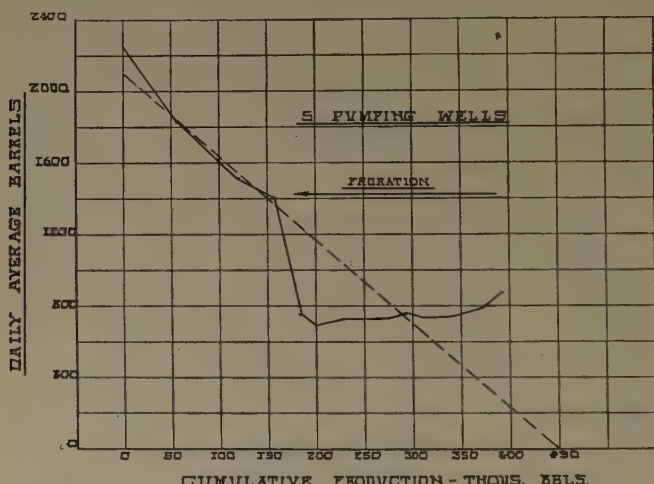

FIG. 17.—RATE-CUMULATIVE CURVE OF THE LEASE IN FIG. 16, SHOWING INDICATED INCREASE IN ULTIMATE DUE TO PRORATION.

It is significant that in the case of both the lease in Fig. 16 and the general curve of a neighboring field producing from the same horizon the rate of increase of water was appreciably slower after the beginning of proration.

Fig. 17 is a rate-cumulative curve of the lease just mentioned. The wells have already produced nearly 400,000 bbl. and there is every indication that the ultimate will be much more than the 450,000 bbl. indicated before proration.

Proration sometimes proves disastrous to wells of low structural position. For example: Well A drilled the Upper and Lower Wilcox sands, having an initial production of 1000 bbl. of oil and a show of water on the lift. Shortly thereafter this well was shut in for proration and well B, the direct offset, 12 ft. higher structurally, and with 15 ft. greater penetration into the Lower Wilcox, came in for an initial production of 2160 bbl. of oil on the lift. Two weeks after shutting in, well A was

opened to find 2000 ft. of water in the hole, which could not be lowered below 500 ft. Later the well made as much as 180 bbl. of oil from the Upper Wilcox and 700 bbl. of water from the Lower Wilcox.

In many fields, wells of high structural position eventually become edge wells because of encroaching water. This, then, would demand special methods of operation under proration to obtain maximum recoveries. Continuous production under pressure control rather than alternate production open and closed (intermitting) might delay the appearance of water. In Seminole the water flood line was retarded by use of the gas-lift on at least one lease. Pumping wells of similar structural position along the water front reached their economic limit much sooner. Several Earlsboro wells having low fluid levels actually increased in potential and daily production under the so-called intermitting during proration. Apparently the adverse effects of proration in one field cannot be generalized, but it is believed that a close study of field conditions and operating methods is necessary to reduce losses in edge wells to a minimum.

Conclusions

In many cases in fields operated under proration agreement, deferred production will be recovered. The flattening of numerous potential production and actual production curves indicates an increase in the ultimate recovery of wells favorably situated. The ultimate recovery of some wells, especially edge wells, will be decreased. By a close study of field conditions and operating methods, such losses can be reduced materially.

Proration affords opportunity for study and practice in methods of operation. The very fact that a company cannot produce to capacity encourages experimentation in pressure control and water control, which doubtless will lead to more efficient operation and greater ultimate recovery.

DISCUSSION

(J. B. Umpleby presiding)

M. Albertson,* Dallas, Texas (written discussion).—This paper refers to one phase of an interesting and important subject. The larger subject might perhaps be well styled: The Effect of the Rate of Production on Decline, Potential and Ultimate Production of Oil Wells. In speaking of the rate of production in this connection, we must not lose sight of the fact that gas is one of the substances produced and that we must look deep enough into the problem to see the result of any method of production on the rate of gas production as well as the rate of oil production. The ratio of gas to oil under the various rates and methods of production may well prove one of the most significant factors, if not indeed the most significant one of all, in explaining the results which are obtained.

* Shell Petroleum Corporation.

I take it that it has been the intention of the authors of this paper to limit themselves to a discussion of the actual effects obtained under proration in various areas. Presumably the records as to gas production before, during and after proration were not available, otherwise they would have been presented along with the other data.

We must recognize, I think, that the rate at which proration is applied may be very significant as to whether it is helpful or otherwise from the standpoint of efficient recovery from the sand. Furthermore, proration as applied in the past has been, I believe, almost wholly determined by the market demand for oil and little or nothing has been done from the viewpoint of what rate of production would be wise for the best possible ultimate recovery. I do not mean to say that the rate of proration should necessarily be determined in such a way as to give maximum ultimate recovery, but certainly until we investigate the situation from this angle we have not gone far toward a real understanding of the essential problems involved in proration. As it is now, proration is established at an arbitrary rate and carried out by methods which perhaps are not most efficient, particularly with a view to the production of gas, so that the effect on decline, potential and ultimate production may be good, bad or indifferent, dependent upon the rate at which proration is established and the way in which this rate conforms to the most efficient rate for the withdrawal of oil and gas in any particular well or pool.

G. B. Corless,* Houston Texas.—We shut down one day a week on our Gulf Coast salt dome wells, during two months this spring, and practically no effect was observed on the production either during or after the curtailment was put in effect. Previously it was thought that these wells would be entirely ruined by shutting them down, but our experience for eight successive Sundays showed practically no adverse effect.

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* Petroleum Engineer, Humble Oil & Refining Co.

Repressuring and Initial Pressuring

By H. C. George,* Norman, Okla.

(Tulsa Meeting, October, 1930)

Since 1911, when J. L. Dunn first used compressed air for repressuring depleted oil sands in southeast Ohio, the rejuvenation of many depleted oil fields has been directly due to repressuring by means of air or gas.

Developments in repressuring in recent years have resulted in its successful use in the early life of some deep, high-pressure oil fields, conserving the natural gas dissolved in and associated with the oil by returning it to the producing oil sand after it has been compressed above the existing rock pressure of the reservoir. One of the most successful operations of this type is that of the Humble Oil & Refining Co., on the DeWalt salt dome at Sugarland, Texas.

I quote from a personal communication with reference to this field: "Structurally, the field is dome-shaped, having a closure of approximately 350 ft. Production comes from a sandy shale interbedded with a clean sand and lying over a cap rock which is about 3400 ft. deep on top of the structure."

A feature of the operation of this field is the production of the required amount of oil with the minimum of gas production. Wells on top of the dome have high gas-oil ratios, while those down structure have lower ratios, depending upon the distance of the well from the peak. To date, it has been possible to produce the oil needed from the wells circling the dome above the water zone and below the gas zone, and in this manner the average gas-oil ratio has been kept low. The gas from all separators is turned into a gas system which serves the entire field. From this system, all drilling rigs and utilities requiring gas for a fuel draw their requirements, and the remainder of the gas (about two-thirds of the production) is delivered to a compressor plant which boosts the pressure until it can be returned to the sand at the top of the dome where the rock pressure is 1400 lb. per square inch.

"The Sugarland wells produce through 2-in. tubing with a ⅜-in. choke in one wing of the well-head manifold. The pressure builds up as high as 1300 lb. per square inch on the casing while on the tubing it varies from 0 to 900 lb. per square inch, depending upon the amount of gas produced with the oil."

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* Director, School of Petroleum Engineering, University of Oklahoma.

Sugarland and other unit operations of similar type are examples of repressuring which, due to the early application of pressure and the effectiveness of the results secured, approaches initial pressuring.

I think that most petroleum engineers believe that the decline in the flow of oil wells producing from sand reservoirs chiefly is due to the escape of gas in excess of the initial gas-oil ratio, because of a high differential in pressure between the initial rock pressure and that existing in the well at the face of the sand. This excess gas in the form of bubbles which develop in increasing number and size as the well opening is approached and occurring in the sand at increasing distances from the well as the pressure differential increases with the age of the well, presents a constantly growing obstacle to production.

Admitting that under modern operating conditions pressure control has conserved as much gas and has increased the ultimate production over what would have been secured under open-flow conditions, it has at best only decreased the degree of the obstruction to flow, because the existing pressure differential is below the initial rock pressure of the sand and permits the gas to come out of solution within the sand.

After observing the difference in the pressure gradients secured by Prof. W. F. Cloud[1] while flowing gas-saturated oil and dead (gas-free) oil through packed sand, it occurred to me that in new oil fields the experiment might be tried of operating oil wells with no wells producing at less than the initial rock pressure. Theoretically this can be done by building up a differential pressure above the initial rock pressure by the use of compressed gas or air introduced into key wells and at the same time at the producing wells maintaining a back-pressure on the sand equivalent to the initial rock pressure. The building up of this differential at the key wells should cause the oil to move towards the producing wells, with none of the gas coming out of solution within the sand, and with the same condition of flow as when dead oil or oil free from gas flows through a sand. With constant differential above the initial rock pressure, the resulting condition of flow might approach the same constancy of output shown by wells under hydraulic control.

In an oil sand of fairly uniform texture, theoretically, at least, initial pressuring should permit the recovery of all of the oil except the part that is retained by adhesion to the walls of the reservoir, and the reservoir should remain, after the exhaustion of the oil, filled with commercial natural gas, at or above the original rock pressure of the field. However, if some of the gas produced with the oil is used for surface needs, extraneous gas will have to be introduced during the life of the field, in order to

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[1] W. F. Cloud: Variation of Pressure Gradient with Distance of Rectilinear Flow of Gas-saturated Oil and Unsaturated Oil through Unconsolidated Sands. *Trans.* A. I. M. E., Petr. Dev. and Tech. (1930) 337.

maintain the initial rock pressure. Frequently gas from upper sands, which would otherwise go to waste, could be used for this purpose.

Initial pressuring should have the following advantages: (1) Periods of flush production would be eliminated from oil fields; (2) periods of overproduction due to excessive flush production would be minimized; (3) paraffin and similar deposits would be decreased and perhaps prevented in oil wells; (4) sand troubles due to cutting of well connections would be at a minimum; (5) there would be no waste of gas; (6) gas would be retained as a national resource after the exhaustion of the oil.

Through the cooperation of the various oil companies, the American Petroleum Institute, the Petroleum Division of the A. I. M. E., the American Bar Association and various state and federal bureaus and commissions, some progress has been made towards an understanding of what is required for petroleum conservation and the stabilization of the petroleum industry.

The advantages of unit operation are coming to be recognized as a means towards these ends. Perhaps initial pressuring or something approaching it may play a large part in the proper development, regulation and operation of federal, state and privately owned oil lands, to secure ultimately a stabilized industry.

Problems in Proration on the Basis of Gas Energy

By Eugene A. Stephenson,* Rolla, Mo.

(New York Meeting, February, 1931)

Critical analyses of the work expended in producing oil by the utilization of gas energy have appeared in the publications of Shaw,[1] Pierce and Lewis,[2] and Herold,[3] authors who have ably discussed the factors which must be taken into consideration in comparing energy consumed per barrel in various wells which are flowed by means of gas-lift.

However, two distinct phases of oil production are concerned with the ratio of gas energy consumed to oil produced. One of these phases is the gas-lift, which utilizes the differential gas pressures for the purpose of flowing oil, whether these pressures be natural reservoir pressures or be induced by artificial compression of gas or air. The other phase has to do with prorating oil production in pools which are operated either as units, or are subject to such restrictions as those imposed at Oklahoma City by the Corporation Commission, or by similar controlling groups in other fields. An abundance of literature is available relative to the problems of flowing wells by gas-lift, but the first suggestion that the energy of the gas within the oil and gas pool might serve as a basis for proration, appeared in the timely article by McWilliams.[4]

Much of the dissatisfaction with proration in certain fields arises because some operators feel that besides the hazard to the wells which accompanies the test, the method of allocating production on the basis of the "potential" gage is inequitable and gives some operators a distinct advantage over others.[5] The most severe penalty may be exacted from the most progressive operators or those who attempt to produce their oil with a minimum quantity of reservoir gas. If no difficulties ever developed in drilling, shutting off water, or in well completion, it might

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* Professor of Petroleum Engineering, School of Mines and Metallurgy, University of Missouri.

[1] S. F. Shaw: Energy Contained in Petroleum Gas. *Min. & Met.* (Jan., 1926) 10.

[2] H. R. Pierce and J. O. Lewis: Principles of the Air-gas Lift as Applied to Oil Production. Petroleum Development and Technology, A. I. M. E. (1927) 19.

[3] S. C. Herold: Analytical Principles of the Production of Oil, Gas and Water from Wells. Stanford Univ. Press, 1928.

[4] J. R. McWilliams: Gas Energy Proration to Prevent Waste. *Oil & Gas Jnl.* (Nov. 6, 1930).

[5] T. V. Moore: Determination of Potential Production of Wells Without Open Flow Tests. *Oil Weekly* (Nov. 14, 1930), 44.

be possible to finish all wells with the same size casing and tubing and thus make the "potential" gage basis more equitable, but the industry has not yet reached the stage where all such hazards can be avoided. Hence, any method which will be fair to all oil and gas producers, will avoid waste and will not require additional operating expense should be welcomed by all sound operators.

McWilliams[6] definitely recommends that oil production from any particular pool be prorated on the basis of the total available gas, instead of the method of "potential capacity" of the individual wells. He suggests that each individual operator be permitted to produce a certain volume of gas along with the oil during a definite period, and that it might be feasible to allocate to each operator during any proration period a specific volume of gas for each acre under his control.

The method proposed by McWilliams is inherently sound, in that it recognizes that the expulsive force which brings the oil to the surface is the differential gas pressure. Even in reservoirs which are under hydraulic control, these are, for the most part, also under high gas pressure, and during the flush stage of production the dominant productive force is the differential gas pressure.

The total pressure and the total volume of gas within the reservoir, whether as free gas or as gas dissolved in the associated oil, or both, are fixed quantities at the time development of the field is commenced. Also, if the reservoir is continuous the initial closed-in pressures will be practically the same everywhere, unless the sands be of great thickness, as in the case of the California productive zones. During the development and exploitation of the field the changes in pressure and volume, which take place, are such that the following relation is maintained, providing the actual size of the reservoir itself does not change:

$$P_1V_1 = P_2V_2 = P_3V_3 = K$$

where P_1, P_2, and P_3, represent successive values of the reservoir pressures, and V_1, V_2, and V_3, represent the corresponding volumes of the gas measured at the successive pressures, and K is a constant.

If the pressures are expressed in pounds per square foot, instead of pounds per square inch, the work in foot-pounds W, performed by a gas in expanding isothermally is then given by the equation:

$$W = P_1V_1\int_{V_2}^{V_1}\frac{dV}{V}$$

where P_1 represents the larger pressure, P_2 the smaller pressure, and V_1 the smaller volume and V_2 the larger volume.

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[6] J. R. McWilliams: *Loc. cit.*

After integration the equation becomes:

$$W = P_1V_1(\log_e V_2 - \log_e V_1)$$

but since $P_1V_1 = P_2V_2$

$$W = P_2V_2 \log_e \frac{V_2}{V_1}, \text{ or } P_2V_2 \log_e \frac{P_1}{P_2}$$

The maximum quantity of work which can be obtained from the gas within the reservoir then depends on the reservoir pressure, the volume of gas within the reservoir and the pressure differential between the reservoir and the point of gas exit. If, for example,

P_r = the reservoir pressure in pounds per square foot, absolute.
V_r = the volume of gas within the reservoir, cubic feet at reservoir pressure.
P_w = the pressure of the gas at the well head expressed in pounds per square foot, absolute. (Or if the separator or trap is placed close to the well the latter pressure may be used.)
V_w = volume of the gas in cubic feet at pressure P_w.

the maximum quantity of work which will be performed by the gas in expanding pressure P_r to pressure P_w will be represented by the equation:

$$W = P_rV_r \log_e \frac{P_r}{P_w} \text{ or } P_wV_w \log_e \frac{V_w}{V_r} \text{ or } P_wV_w \log_e \frac{P_r}{P_w}$$

The reservoir pressure, P_r, can be measured, the volume, V_r, can be estimated early in the life of the field using methods to be outlined presently, the volume of the gas V_w, converted to standard conditions, can be specified by the proration agreement, while the pressure P_w, can be left to the discretion of the individual operator. Thus all of the variables can be known. Under the plan proposed by McWilliams, a fraction of V_r—the reservoir gas, corrected to standard conditions—can be allocated to each acre per day for any proration period, and this quantity can be modified at the discretion of the controlling board.

In actual operating conditions the maximum quantity of work cannot be realized due to slippage, friction within the sand, casing and tubing, the fact that the gas will be discharged into separators at some pressure higher than atmospheric, and the failure to reach perfect isothermal relations, etc., but the proportion of such work which is realized can to a large extent be determined by the efficiency of the operator. This point alone is one of the strongest arguments in favor of this method of proration. Instead of being penalized for efficient operation, as may be the case when potential gages are used as the basis for proration, the efficient operator is rewarded by increased production while the inefficient operator suffers his just penalty in smaller production per unit of gas utilized.

Some objection has already been raised to proration or unit pool operation because one operator feels that his organization is possibly

more skilful in obtaining the maximum quantity of production with a minimum quantity of gas. Such pride is wholly justifiable and by allocating to each individual operator a quantity of gas proportional to his acreage holdings, every inducement is offered to make the greatest possible use of the energy which is available.

This method also readily takes care of those individuals who attempt to confine their drilling operations to small tracts of one or two acres or less, hoping to utilize the gas pressure of near-by larger areas, and derive their oil from adjacent tracts. If such operators can only take from their wells daily a quantity of gas which is proportional to the number of acres under their control, they will find it difficult to extract oil from the leases of their close neighbors. It might also be desirable to establish arbitrarily a limited number of acres as the drainage area per well.

The history of the production is replete with examples of the excessive development costs that have accompanied competitive drilling in new fields. Besides the waste of time, money and oil, it is certain that much of the oil produced both by the wells which are located on small tracts and by their attendant offset wells does not come from the small tracts themselves but migrates from adjoining areas due to the high differential pressures which are established. Such closely spaced wells commonly yield a minimum amount of geological or engineering data, and give little or no indication of the lateral extent of the new field, the mean sand thickness, or porosity. If, on the other hand, the pool should be operated under the control of a unit group, the subsequent wells instead of being drilled as offsets could be drilled at such points as to bring to the operators the largest amount of essential information—information which would be of value in determining the extent of the field, the thickness of the sands, the subsurface geological structure, the probable oil and gas reserve, and the total available energy of the pool.

In order to make proration most equitable it would be highly desirable early in the life of the field to make some sound estimate of the total quantity of available gas, V_r. This calculation, which should be referred to some standard basis of measurement, can be made as of the date of the initial completion, or of any other basic date, where adequate records have been kept of the initial pressure of the reservoir and the quantity of gas withdrawn.

Various methods of estimating gas reserves have been developed in recent years, which have attained a reasonable degree of accuracy. These methods are based either on the rock pressure decline, where both rock pressure and production data are available, or on the rock pressure, the thickness, porosity, and the extent of the producing sand. For the most part these reserves take into consideration only the fixed gases, or those which are gases at ordinary temperature and pressure, methane and ethane.

The rock-pressure production-decline method, as explained by Davis,[7] has been demonstrated to be of great value, both in finding the initial pressure of fields whose initial pressures were not recorded but from which all gas has been metered, or in calculating the total quantity of gas withdrawn prior to the metering period if initial and subsequent pressures are known.

In Fig. 1 the average midyear rock pressures of all the wells in a small section of a West Virginia field are plotted for successive years as graph *AB*. The average pressures at the end of each year are obtained directly from the curve. The average year-end pressures are then plotted against the cumulative production, resulting in graph *DF*. The total past production can be obtained by extending the curve backwards to point *C*, which corresponds with the initial pressure in the pool, while the future production is represented by the extension of the graph, *FG*.

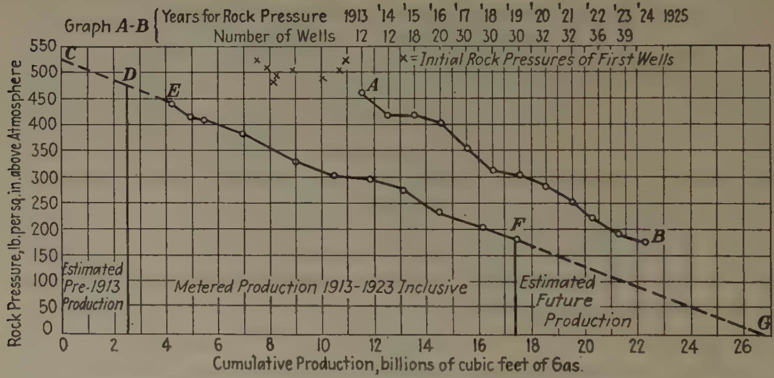

FIG. 1.—ROCK PRESSURE AND ROCK-PRESSURE PRODUCTION GRAPHS; *X* FIELD, INJUN SAND, AREA *O*. (AFTER RALPH E. DAVIS.)

AB, average annual rock-pressures; *CD*, rock-pressure production before 1913; *DF*, rock-pressure production 1913–1923; *FG*, rock-pressure production 1924 to economic limit.

Due to its greater compressibility at higher pressures it would be expected that the gas produced per pound drop in pressure early in the life of the field, when the pressure is high, would be greater than that produced after the pressure had shown a considerable decline. Expressed graphically, this would mean that the portion of the curve *CDE* (Fig. 1) would be flatter than the portion of the curve *EF*. However, actual observations in this and many other of our important gas fields fail to disclose any effects of compressibility, when the yields per pound drop in pressure are compared. The Monroe field, for example, whose initial pressure was 1030 lb. per sq. in., shows the same yield per pound

[7] R. E. Davis: Methods of Estimating Gas Reserves. *Oil & Gas Jnl.* (June 18, 1927) 125.

drop in pressure in declining from 1000 to 950 lb., as in declining from 850 to 800 lb. No adequate explanation for this fact is as yet vouched, although there is a possibility that a considerable quantity of gas is adsorbed upon the surface of the sand grains and may be given up from these surfaces at such a rate as to compensate for the compressibility factor.

No matter which method of computing the reserves is used it is essential to determine the average rock pressure and in order to do this

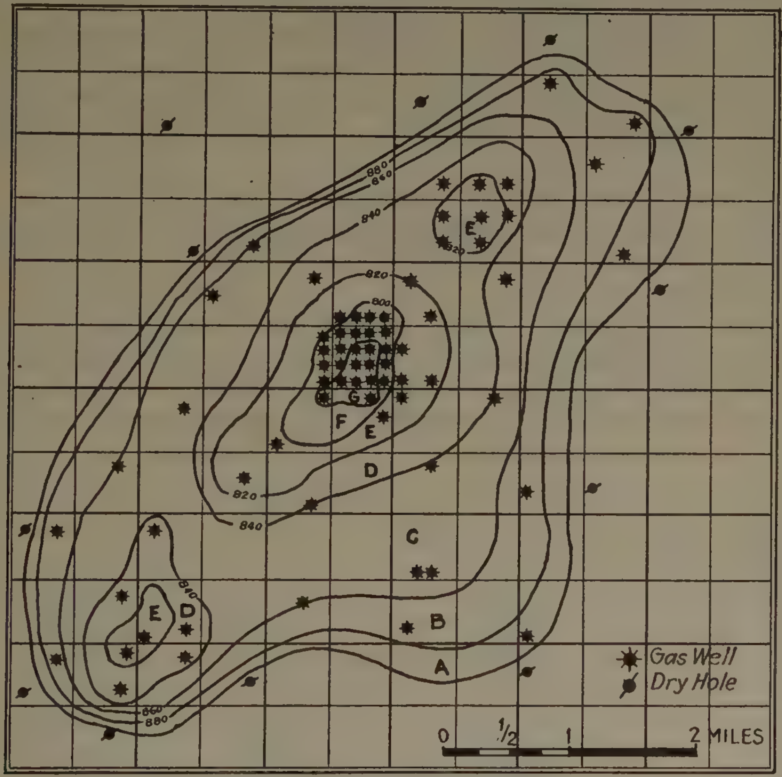

FIG. 2.—ROCK-PRESSURE ZONES.

Area *A*, 890 to 880 lb. absolute; *B*, 880 to 860; *C*, 860 to 840; *D*, 840 to 820; *E*, 820 to 800; *F*, 800 to 780; *G*, 780 to 760.

for large fields consideration must be given to the intensity of the development in different parts of the field. Where extraction of gas and oil have taken place most rapidly the decline in pressure will have been most pronounced. Hence very low pressures may be produced in certain parts of the field while other parts still show the original reservoir pressure. Further, the size of the low-pressure area may be relatively small and yet contain the largest number of wells, while the high-pressure area may embrace the greater portion of the field and contain but a small

number of wells. On this account the average rock pressure of the field cannot be obtained by adding the total pressures of the wells and dividing by the number of wells, but the areal extent of the high and low-pressure areas, as well as the pressures therein, must be taken into account. This condition has been successfully met by drawing contours—isobars—connecting points of equal pressure within the field. By using a contour interval representing a pressure differential of 20 to 25 lb., the field can be divided into areas which show the pressure gradient by 20 or 25-lb. intervals. After measuring with a planimeter the size of these various areas, it is possible to compute a weighted average rock pressure for the entire field without making use of the number of wells in the different pressure zones. Where pressure variations with depth take place a similar method can be applied for the determination of the average pressure.

Knowing then the average decline in pressure and the quantity of gas taken from the reservoir during this decline in pressure, it is possible to compute the remaining gas reserve, referred to any specified basis of measurement.

For example, in Fig. 2, if the area of each zone *A*, *B*, *C*, etc., be multiplied by the average pressure of the zone and the products added together and divided by the total number of acres in the pool, the result is the average pressure of the pool as of the date of the pressure test.

Area	Number of Acres	Average Reservoir Pressure, Lb. per Sq. In. Absolute	Product
A	1,645	885	1,455,825
B	2,350	870	2,044,500
C	3,610	850	3,068,500
D	1,951	830	1,619,330
E	1,172	810	949,320
F	313	790	247,270
G	113	770	87,010
Total.............	11,154		9,471,755

Total product, 9,471,755, divided by 11,154 = 849 lb., which is the weighted average pressure of the reservoir gas.

Since the decline in pressure is 51 lb., therefore, $51/890$ of the total gas has been withdrawn, leaving $849/890$ in the reservoir. If the quantity of gas extracted has been 6 billion cubic feet the total gas remaining in the reservoir down to atmospheric pressure is therefore 104.7 billion cubic feet.[8] This result can also be obtained graphically as shown in Fig. 3.

[8] The first public presentation of this method was made by Ralph E. Davis at the Pittsburgh Meeting of the American Institute of Mining and Metallurgical Engineers, Oct. 6, 1926.

Where no free gas is present in the reservoir, but only gas in solution in the oil, the quantity dissolved can be determined experimentally or computed by means of the data given by Dow and Calkins,[9] and Beecher and Parkhurst.[10] At pressures of 1000 lb. per sq. in. the solubilities of methane and ethane together range in the neighborhood of 225 cu. ft. per bbl., measured at standard conditions, or about 3.2 cu. ft. at 1000 lb. The latter figure is about 60 per cent. of the volume of a barrel of oil. In a reservoir containing 50,000,000 bbl. of oil under 1000 lb. pressure the volume of the oil is 280,000,000 cu. ft., while the volume of the dissolved gas would be approximately 148,000,000 cu. ft. at reservoir pressure, or 11,000,000,000 cu. ft. at standard conditions.

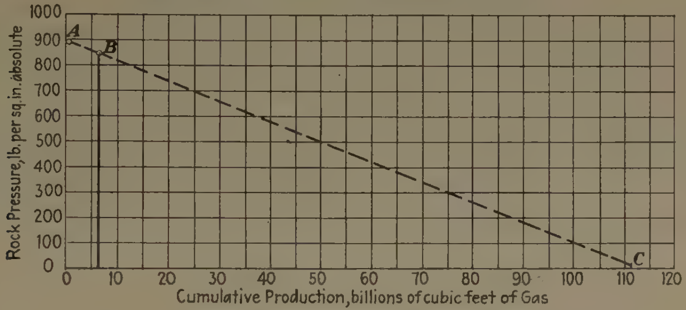

FIG. 3.—ROCK-PRESSURE PRODUCTION GRAPH.
AB, past production; *BC*, estimated future production.

As pointed out by Kollar,[11] certain of the gases present within the reservoir may fall below their critical temperatures and pressures in passing from the reservoir to the well mouth, and instead of exerting a lifting force upon the associated oil, must actually be lifted by the lighter gases with which they are mingled. Hence, it would be desirable for the present purpose to express the total gas content of the reservoir as the quantity of methane and ethane present. In estimating reserves for commercial purposes this procedure is commonly followed and the percentage of heavier hydrocarbons usually ignored.

The methods previously outlined are especially applicable to dry gas fields, and to fields producing both oil and gas, where the volume of the free gas measured at reservoir pressures is relatively large as compared with the total volume of the oil. Where the cubic space occupied by the free gas is relatively small as compared with the volume of the oil it is necessary to take into consideration the fact that any gas which is with-

[9] D. B. Dow and L. P. Calkin: Solubility and Effects of Natural Gas and Air in Crude Oils. U. S. Bur. Mines *Rept. of Investigations* 2732 (1926).

[10] C. E. Beecher and I. P. Parkhurst: Effect of Dissolved Gas upon the Viscosity and Surface Tension of Crude Oil. Petroleum Development and Technology, A. I. M. E. (1926) 51.

[11] R. Kollar: The Significance of Gas-oil Ratios. *Oil Weekly* (May 23, 1930) 28.

drawn from the reservoir produces a decline in pressure, while every barrel of oil removed increases the size of the gas reservoir, which further reduces the reservoir pressure. As a result, the gas expands to fill the space left by the oil and also a certain amount of the gas dissolved in the oil becomes free reservoir gas. Computations show, however, that when small changes in pressure are used in estimating the free gas reserve the quantity of gas which passes out of solution can be neglected. An estimate of the quantity of gas present in solution may also require an estimate of the total quantity of oil in the reservoir.

In order to estimate the free gas in the reservoir under these conditions a knowledge is required of the initial reservoir pressure, some subsequent reservoir pressure, the quantity of gas and oil produced during the above pressure decline, the temperature of the reservoir, the composition of the gas and the solubility of the gas in the oil at several pressures and temperatures. As a check on the above results it is also desirable to know as early as possible in the history of the pool the sand thickness and porosity and the extent of both the oil and gas areas. The Sugarland field of Texas may be used to illustrate the method of estimating the free gas under such conditions.

DATA FOR SUGARLAND FIELD, TEXAS

Initial reservoir, lb.	1,470
April 1, 1930, reservoir pressure, lb.	1,350
Decline in reservoir pressure, lb.	120
Temperature of reservoir, deg. F.	120
Gas produced to April 1, 1930, measured at 16.7 lb. and 60° F., million cu. ft.	2,300
Oil produced to April 1, 1930, bbl.	5,000,000
Oil produced to April 1, 1930, cu. ft.	28,000,000
Gas produced per bbl., to April 1, 1930, measured at base of 16.7 lb., and 60° F., cu. ft.	460
Solubility of gas in oil at 1470 lb., measured at base of 16.7 lb., and 60° F., cu. ft.	211
Solubility of gas in oil at 1350 lb., measured at base of 16.7 lb., and 60° F., cu. ft.	195
Estimated free gas produced per bbl., measured at base of 16.7 lb., and 60° F., cu. ft. 25 per cent. of 460 =	115
Estimated total free gas produced, measured at base of 16.7 lb., and 60° F., million cu. ft.	575
Estimated total dissolved gas produced with oil, measured at 16.7 lb., and 60° F., million cu. ft.	1,725
Volume of free gas produced, reduced to reservoir pressure of 1470 lb., and 120° F., million cu. ft.	7.3
Volume of dissolved gas produced, reduced to 1470 lb., pressure and 120° F., million cu. ft.	21.9

The volumetric changes taking place under the above conditions are illustrated in Fig. 4. Area *ACGE* or V_1 represents the original volume

of free gas at 1470 lb. pressure and 120° F. The temperature is considered constant. Area *BCGF* represents the volume of free gas extracted, and area *BDHF* shows the space occupied by the oil which was removed from the reservoir. Since the volume changes illustrated resulted in a drop in the reservoir pressure from 1470 to 1350 lb. the following equations may be written:

$$\frac{ACGE - BCGF}{ACGE - BCGF + BDFH} = \frac{1350}{1470}$$

or

$$\frac{V_1 - 7.3 \times 10^6}{V_1 - 7.3 \times 10^6 + 28 \times 10^6} = \frac{1350}{1470}$$

Solving for V_1

V_1 = 322.3 million cubic feet as original volume of free gas at 1470 lb., and 120° F.

Hence, 315 million cubic feet is the volume of free gas remaining in the reservoir measured at 1470 lb., and 120° F., or 24.8 billion cu. ft. at 16.7 lb., and 60° F., as of April 1, 1930.

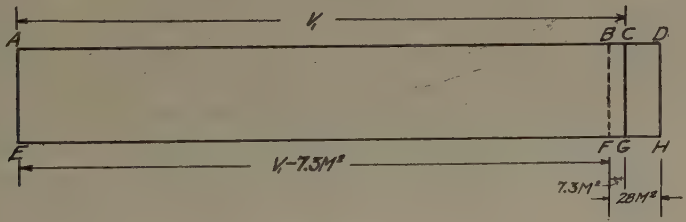

Fig. 4.

In the calculations above it has been assumed that of the 460 cu. ft. of gas produced with each barrel of oil only 75 per cent. was dissolved in the oil and that the balance, 25 per cent., is free gas. This assumption may not be strictly true, but it can be shown that if all of the gas produced—100 per cent.—had been dissolved in the oil, the volume of the free gas remaining in the reservoir would still be approximately 24.8 billion cubic feet measured at 16.7 lb. and 60° F.

To the reserve of free gas should be added the quantity dissolved in the oil. Where the extent of the oil reservoir is known the latter can be estimated by using the porosity—saturation method in conjunction with data as to the solubility of the gases.

The gas reserve may be expressed in several ways, such as: (1) total future production down to some assumed pressure limit; (2) future production for the field per pound drop in pressure; (3) total average production per acre; (4) future production per acre per pound drop in pressure.

During the exploitation of the fields additional data may make it necessary to revise the estimated quantity of available gas, which in turn may call for revisions of the proration allowance of gas per unit well or per acre, but such revisions are necessary under almost any scheme of proration and hence are no objection to this particular method.

The problem must also be faced of securing an equitable proration of the income from the pool to the owners of acreage so situated with reference to the geologic structure that only gas and no oil is present under their tracts. The effective energy of the field is ultimately derived from this gas zone and the owners of such acreage should receive some compensation for the utilization of this gas energy in oil production, if they are not to receive their income from the direct sale of the gas to pipe line companies. The writer does not as yet feel confident of a method by which the owners of this gas acreage should be compensated, but is tentatively of the opinion that they might be paid a certain sum per thousand cubic feet of gas withdrawn or injected into the reservoir, or be given a certain fraction of the gross oil produced. It is highly desirable to postpone as long as possible the sale of any gas from the oil leases or from the gas reservoir itself in order to make the maximum use of the energy which nature has provided, plus that which can be added by the injection of the gas.

The most important consideration is to utilize the available gas energy in the production of the oil, realizing that the proper use of this energy will definitely increase the ultimate recovery from the pool.[12]

Under ideal conditions such as those prevailing in the Sugarland field of Texas, which is operated as a unit pool by the Humble Oil & Refining Co., all of the gas except that which is necessary for fuel, can be returned to the reservoir. Under proration each operator could compress the gas to the necessary injection pressure for its return, or could arrange with an adjoining operator to utilize a central compressor station. The cost of such compression, allocated to each individual operator need not be strictly proportional to the quantity of gas returned but can be based upon the pressures at which gas is delivered to the intake side of the compressors. Since the cost of compression is a function of the logarithms of the pressures involved, those who return gas to the compressors at higher pressures should bear a smaller portion of the operating cost per thousand cubic feet of gas handled than those who return the gas at lower pressures.

As in the case of all engineering problems it is most essential that adequate data be available; that records of rock pressures, operating pressures, gas and oil produced, gas analyses, well depths, sand thickness, water movement, initial productions, etc., be carefully kept. If this is

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[12] E. O. Bennett: Effect of the Gas-lift on the Gas Factor and on the Ultimate Production. Petroleum Development and Technology, A. I. M. E. (1927) 168.

done and a definite program of cooperation and of oil and gas conservation be outlined, overproduction can be avoided at the same time that equitable proration is achieved, production costs can be reduced, ultimate recovery increased and waste minimized. The program may appear somewhat drastic, but it is no more so today than were the suggestions of a few years ago that unit operation should supersede the whole policy of competitive development, with its attendant waste of both oil and gas, together with the low ultimate recoveries which obtain under such conditions.

Summary

(1) Every operator will be stimulated to use his allotment of gas energy efficiently, since that will mean more barrels of oil per unit of gas extracted.

(2) Proration on the basis of energy will tend to make every operator alive to the importance of gas conservation, and an effective agent in the reduction of the quantity of gas wasted.

(3) The estimated gas reserves may be compared to the working capital in the financial budget of a large corporation; the expenditure of funds from which profitable returns are expected is analogous to the utilization of the gas energy for the production of oil. Hence a knowledge of the total available energy is of fundamental importance to those in charge of a unit or prorated pool.

(4) With a knowledge of the available gas reserve a definite program of oil production can be outlined, a program which can be readily modified to meet market demands, if such variations become necessary, by merely changing the daily allowance of gas per acre per day.

(5) Under such a program the development of the field can proceed at a rate which will tend to make the decline in pressure approximately uniform throughout, a condition whose desirability has already been pointed out.[13]

(6) By recycling gas a maximum recovery in terms of percentage of total barrels per acre may be anticipated.

(7) Operating costs per barrel can be kept low since the flowing life of the wells will be lengthened.

(8) Compression costs can be equitably apportioned among the different operators.

(9) The recognition that the oil-gas reservoir is the common property of all of the owners of acreage within the pool, and hence that each lease

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[13] See discussion by E. O. Bennett. Petroleum Development and Technology, A. I. M. E. (1928–29) 132.

owner is entitled only to his proportionate share of the gas energy within that pool, should make it possible to secure the ready sanction of this method of proration in the higher courts.

(10) The program is feasible as is shown by the present practice in the Sugarland field in Texas, where the Humble Oil & Refining Co. is utilizing a method which closely approaches the one herein outlined.

Acknowledgments

The writer wishes to acknowledge his thanks to Mr. Wallace Pratt, of the Humble Oil & Refining Co., for generously supplying essential data relative to the Sugarland field, to Mr. J. R. McWilliams of the Skelly Oil Co. for constructive criticism, and to his colleagues, Professors Elmo G. Harris and C. R. Forbes of the School of Mines and Metallurgy of the University of Missouri, for many helpful suggestions.

Chapter II. Production Engineering

Production Engineering in 1930

By W. K. Whiteford,* Tulsa, Okla.

(New York Meeting, February, 1931)

Until the beginning of the year 1930, conditions in the oil industry were such that the production engineer was chiefly concerned with improving the efficiency of development and production technique. Good engineering practice had been adopted to devise and improve methods and materials better suited to drilling for and producing oil and gas. These efforts reduced the hazard and expense of deeper drilling, increased the ultimate recovery from reservoirs and lowered production costs. Equipment was of better design and materials were better suited for the work and were more permanent. These improvements naturally have contributed their share toward increasing the volume of crude oil produced each year.

The industry is now faced with a need for preventing a waste of this natural resource; waste which came as a result of continued reckless drilling of new reservoirs. To make a careful study of this economic problem and to devise methods for correcting these conditions was a logical problem for the production engineer. Much time and study have been devoted to the question, and remedial plans have been suggested during the last year and a half. The principles of unit operation have attracted the engineer's attention, as they present ideal conditions for the most scientific and economical development of an oil field.

Unitization

During 1930 unitization of producing and potentially producing areas has made real progress, and as each new unitized development is agreed upon the objections that loomed so large at the inception of the idea fade into comparative insignificance. Undoubtedly the outstanding example of the efficacy of unitization is the Kettleman Hills project in California. Unitizing this structure, with its almost incredible reserve, is an important step forward in the industry's concerted effort toward conservation. With this partial acceptance of the principles of unit

* Production Superintendent, Barnsdall Oil Co.

operation, the production engineer turned a large share of his attention to the economics and mechanics involved in adopting such a plan. Unitization in itself affords merely an ideal opportunity for the efficient production of oil and gas. Its ultimate success will depend largely, therefore, on the ability of the production engineer clearly to understand and to control the factors that govern the production of oil and gas from a pool.

Production Practice

Curtailment of oil production has become general in nearly every producing area, including the older or so-called "settled" production. This curtailment has focused the engineer's attention on the need for improved methods of establishing "potentials" in flush fields. The effect of proration on the ultimate recovery of a pool has come in for its share of investigation. Where care is used in the utilization of gas, the ultimate production from the reservoir is increased under proration, and the amount of oil thus held back can be considered correctly, "deferred production."

The entire theory of pressure control has undergone critical study. Much previous work on gas-oil ratios, flow efficiencies, beaning and well spacing has been unsatisfactory for two reasons: (1) lack of information as to pressure conditions at the face of the sand, from wells producing under varying conditions, whether artificially or naturally imposed; (2) limited knowledge of the selective solubility of the various gases that are produced with the oil. Without these data there can be no accurate measure of efficiency based on the volume of gas produced with each barrel of oil. Work on these two vital problems is under way. Time and effort are needed to complete the information relative to these projects, but in their solution lies the fundamental law governing the proper use of the gas energy in the production of oil.

Progress in air-gas lift has been confined largely to the flowing of small wells. Application of the intermittent injection of gas through two strings of tubing to prevent pressure being imposed against the sand has resulted in a broadening of the application of gas-lift, as well as the continued operation of wells that have otherwise reached their economic limit. Tubing of oil and gas wells under very high pressure has become common. Special equipment is used for this work and wells with more than 2000 lb. rock pressure have been tubed without the loss of a barrel of oil or a cubic foot of gas. Tubing of wells under pressure has also revived the study of the advantages accruing from the use of the bottom-hole bean. Study of vertical flow velocities has resulted in the designing of flow strings better adapted to the efficient utilization of gas produced with oil.

In a certain type of oil reservoir, encroachment of edge water was found to be an important factor in the ultimate recovery from the pool. Proper regulation of the rate of water advance "up structure" through sands of varying porosities prevents oil from being "trapped" by irregular water encroachment.

Development in pressure maintenance and gas-drive projects has not been extensive, owing to lack of demand for oil. Considerable work continues in the older producing fields. Several experimental projects are under way that should contribute valuable information to the success of future work.

Pumping

The effort to adapt existing pumping equipment to deep pools has continued. Power-transmission machinery of improved design has helped greatly in the maintenance of smooth and continuous operation; endless belts and idlers are common in the newer applications of belted drives; loss of power between the prime mover and the polished rod has been decreased by using chain and gear drives. Proper counterbalancing has become more general through the use of dynamometers and sucker rod service has materially improved. Shock loads have been decreased on all pump equipment and peak loads in the pumping cycle smoothed out. These economies in power requirements have brought about a wider use of electric motors for pumping service.

A great deal of experimental work has been done in studying slow-speed pumping for deep wells. Under certain conditions noticeable increases in daily production have been obtained by the use of this procedure. Slow-speed pumping decreases power consumption in almost every case and materially increases the life of the pumping equipment.

Corrosion of subsurface equipment has become extremely serious in some areas and considerable research is being carried on to develop metals that will better resist corrosion. Steel sucker rods are being coated with various metals, such as lead and zinc, in an effort to protect the rod from corrosive action.

Deep-well pumps designed to eliminate the use of surface rods are under test and several of these pumps have been highly successful under certain conditions. Further development of these pumps presents a real engineering problem that must be solved if the deeper producing horizons of tomorrow are to be produced economically.

Drilling

Proper use of mud-laden fluids in connection with rotary drilling has attracted a great deal of interest and study. This use of mud is not new. From time to time articles dealing with mud have been

published, developing, as a rule, a remedy for difficulties encountered in some special well or area. No concerted study had been made to establish physical standards for mud-laden fluids or for the application of improved practice. The use of rotaries in practically every area under development, the drilling of deeper wells and the encountering of high gas pressures called for a greater theoretical and practical knowledge of the entire subject. Large-scale development campaigns required novel methods and apparatus for the economical and practical conditioning and distributing of mud-laden fluids. Careful investigations of the properties of mud and the analysis of the character of mud required for various drilling conditions have developed improved methods for the treatment of mud. These better methods have brought into use several pieces of equipment familiar in mining practice. Vibrating screens and classifiers have been used successfully in properly conditioning mud. Admixtures are being used in controlling the properties of mud, so that almost any desired combination of viscosity and weight can be obtained by the proper mixture of special materials. Chemical reagents capable of changing the consistency without affecting the weight have been developed and used to some extent, but the cost of the chemical has been a deterrent to their general employment. The importance of proper mudding in preventing blow-outs, lost circulation, stuck drill pipe and excessive wear on bits and slush pumps justifies further work on this complex subject. Though much progress has been made during this year, a wider dissemination of the facts already known would result in an improvement in present field practice and provide much information for future study.

Test holes drilled by rotaries in isolated areas where fuel is costly and the supply of water is limited or not suited to boiler requirements have made desirable the use of power other than steam. Multiple-cylinder gasoline and full Diesel engines, connected either directly to the draw works through a reversible clutch or to an electric generator, have been used successfully. Fuel costs on wells so drilled have been remarkably low. The continuity of service and the rate of drilling compare favorably with steam equipment. Steam power economies, through the use of increased operating pressures and superheated steam, are being studied in connection with the steam consumption of engines and pumps of different designs. This work has led to the study of the inherent possibilities of the steam turbine for rotary drilling, particularly in the operation of the mud pumps. A test on the feasibility of using a hydraulic turbine as a source of power for rotary draw works is also under way. Time studies of the different operations in rotary drilling have aided greatly in the correlative study of the performance of the numerous items included in a rotary rig.

Summary

Crude oil potentials increased during 1930 to a point at which the entire industry realized the serious need of devising a plan that would not only balance supply against demand but prevent a recurrence of the present uneconomic situation, and thus achieve permanent stability.

Managements of oil companies realized that any intelligent solution of this problem of production control would have to be founded on good engineering practice. The production engineer was thus afforded an opportunity to broaden his field of service. To his work of improving and developing production methods has been added the dimensional factor of the economics of supply and demand. This work has just started and is certain to grow, and in the solution of this problem the production engineer will have his greatest opportunity to apply sound engineering to the production of oil.

Methods and Effects of Unit Repressuring in the Cook Pool

By Graham P. Crutchfield,* Albany, Texas

(New York Meeting, February, 1931)

The W. I. Cook pool in Shackelford County, Texas, has been the subject of a number of papers and articles. Its unique position both as to operation and development has made it an ideal location for unit repressuring. The major portion of the pool is located on the W. I. Cook ranch and most of the oil leases are owned by Roeser & Pendleton,

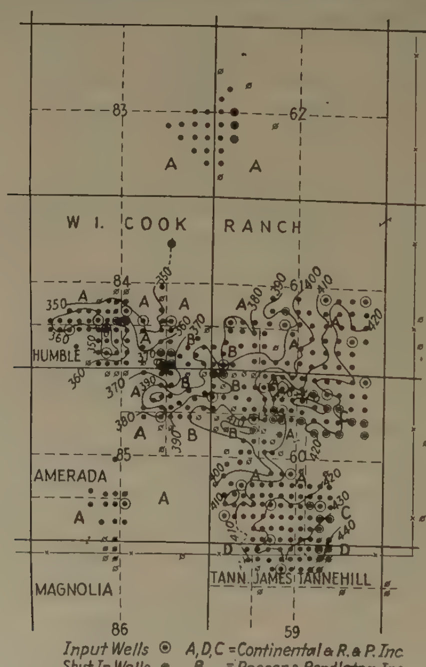

Fig. 1.—Producing sand contours, Cook pool, Jan. 1, 1931.

Inc. and the Continental Oil Co. and operated by Roeser & Pendleton, Inc. The Humble Oil & Refining Co. and Tom James operate producing leases which have a vital bearing on the unity of the pool. Both have cooperated in the repressuring project. Practically the entire royalty is owned by Mrs. W. I. Cook and she has given the operators her entire cooperation in all phases of unit repressuring.

* Chief Engineer, Roeser & Pendleton, Inc.

The majority of wells are producing from the Cook sand, which is one of the Cisco series, a subdivision of the Pennsylvanian. The average depth of the producing sand is 1300 ft. and its average thickness is 18 ft. A porosity of from 30 to 35 per cent. has been indicated by a few unsatisfactory cores. There is a wide variation (from 5 to 30 ft.) in the thickness of the producing sand body and in some localities it is badly broken.

Fig. 1 shows the present development of the field and also subsurface contours of the Cook sand.

Installation

A vigorous drilling campaign was instituted immediately after the completion of the discovery well on Feb. 19, 1926, resulting in the completion of 142 wells by the first of May, 1927. The production from these wells was 8700 bbl. of oil and 7,000,000 cu. ft. of gas per day. Experiments conducted during this time with the aid of portable compressors having shown the feasibility of repressuring the field, it was decided to proceed with the project at once.

To simplify cost accounting and unify operation, this work was placed in the hands of the gasoline department, with the agreement that the producing divisions pay 3 c. for each 1000 cu. ft. of gas returned to the sand. Three 190-hp. direct driven gas-engine compressors were installed in the gasoline plant. These machines take residue gas and fractionator vapors from the gasoline plant at 30 lb. pressure. They are capable of delivering 4,000,000 cu. ft. per 24 hr. at 400 lb. pressure. Main and distributing lines were laid from this central station to all parts of the field where injection gas was needed. Each individual injection well was equipped with an automatic volume controller, high-pressure stuffing box casinghead, and open-ended string of tubing.

To meet the need for accurate records of any field being produced under repressuring conditions, a system was installed which has proved very satisfactory. The lease is gaged by batteries, the average condition being one battery to 15 producing wells, and at each battery a test tank and test trap were manifolded to the wells producing into that battery. Each day one well is switched so that its oil production and gas volume may be measured with this testing equipment. This results in a 24-hr. test of both oil and gas from every well on the property at least twice each month.

Operation

Beginning July 15, 1927, gas has been continuously returned to the producing formation and to date has reached a total volume of 3,750,000,000 cu. ft. A brief summary of the actual operating problems encountered, and the remedies applied, with the hope of solving them, may be of interest. The first injection wells were located on the highest part of the

structure. These proved very unsatisfactory. The producing formation has a dip of only 50 ft. to the mile and, consequently, no sharp line of demarcation between the oil areas and gas areas. Gas injected at the top of the structure immediately channelled as far as five locations down structure. This led to the abandonment of the original injection wells and the location of new ones distributed as regularly over the entire producing area as the sand conditions would permit. It was found advisable to use for injection purposes old oil wells whose original low rate of production indicated a tight sand condition. This was done so that the oil movement might be toward more permeable portions of the sand. Immediately it was discovered that there was a wide difference in the pressure required by various wells for the injection of gas. Some would take a satisfactory volume at a pressure only slightly exceeding the rock pressure, while others would not take any gas at the highest pressure that could be maintained with the equipment available. Between these two extremes, wells of every degree of resistance were encountered. Steam and hot water injected and agitated by means of the tubing left in the wells for that purpose frequently would make it possible to use wells that otherwise would have been abandoned as injection wells.

The first winter water vapor in the gas caused trouble by freezing at various points throughout the system. Line breaks in cold weather frequently caused a freeze-up of the complete distributing system, due to the evaporation and expansion of the liquid propane and butane present. This was particularly difficult to handle in buried lines because it was impossible to get at them to thaw them out. Repeated occurrences of this particular trouble leave some doubt as to the actual value of buried lines for this service. The installation of a gas after-cooler and scrubber at the compressor station prevented such frequent occurrence of these troubles. Freezing of the automatic volume controllers was remedied by installing a heater ahead of the control valve at each well. This heater consists of a hot-water-to-gas heat exchanger in which temperature is maintained by the thermosiphon circulation of water heated in a small boiler placed at a safe distance from the control apparatus. The exchanger itself is uninsulated and installed with the rest of the apparatus in a double-walled meter house, which was built to prevent freezing of the controller block valve and actuating gas-pressure regulator. There was trouble with injection wells that would run for long periods of time with a normal injection pressure and then gradually build up resistance until it was no longer possible to inject gas at the highest pressure that the equipment was capable of maintaining. A vigorous washing of the producing sand with boiling water and steam would invariably restore such wells to their previous low resistance. The well would operate normally for several months, when the same condition would again arise.

An investigation disclosed that fine rust from the distributing lines was being deposited in the bottom of the injection wells and sealing off the sand. Filters installed at each well to catch the rust have proved a permanent remedy. The volumes injected in the various wells have varied from 25,000 to 300,000 cu. ft. per 24 hr., depending on the rock pressure it was desired to maintain.

The rock pressure of each injection well is obtained at least once a month by the following method: A recording pressure gage is attached to the well head and the supply of injection gas is then shut off. The

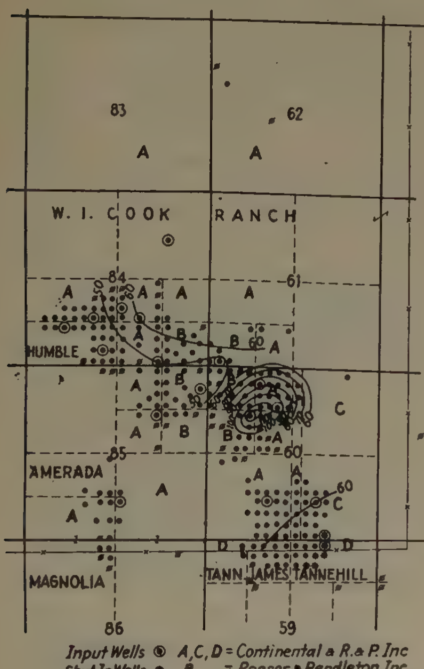

FIG. 2.—ROCK PRESSURES, COOK POOL, JUNE 1, 1928.

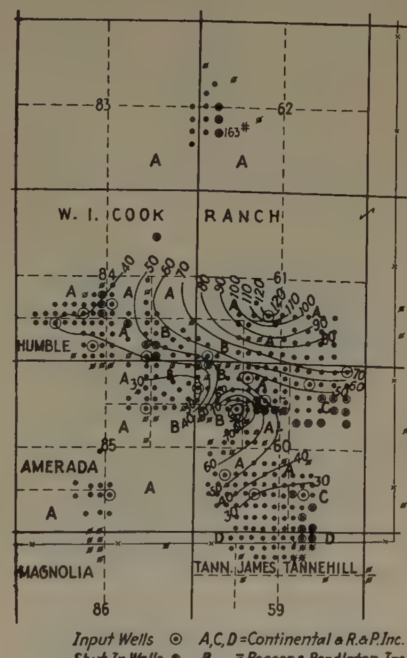

FIG. 3.—ROCK PRESSURES, COOK POOL, JAN. 1, 1929.

recorded pressure falls at first rapidly and then more slowly to a final constant figure. This is taken as the rock pressure. This method is open to theoretical objections but when used for practical purposes is simple and satisfactory. Rock pressures and injection volume curves are part of the permanent record of each injection well (Fig. 12). The repressuring of adjoining leases of different ownerships is controlled by maintaining the original difference in rock pressure between them.

There are two main factors controlling rock pressure in a producing field; namely, the amount of gas returned to the producing formation and the amount of gas taken from the same formation. The last factor is governed by the gas-oil ratios of the producing wells. For reducing

these ratios, a number of methods of control have been tried, including back-pressure, casing gas anchor, raised working barrels, part-time pumping and variable strokes. Of these the last proved most successful, and each pumping well is now equipped with a swing post which has adjustments that permit varying the stroke of the pumping jacks to suit the producing conditions.

This pool has had two major proration periods. The first started May 18, 1927 and continued until Nov. 1, of that year. Repressuring started during that time. The second period of proration began on Jan.

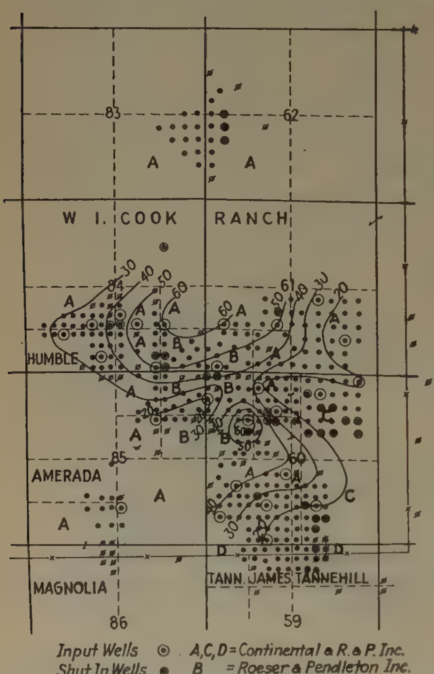

FIG. 4.—ROCK PRESSURES, COOK POOL, JAN. 1, 1930.

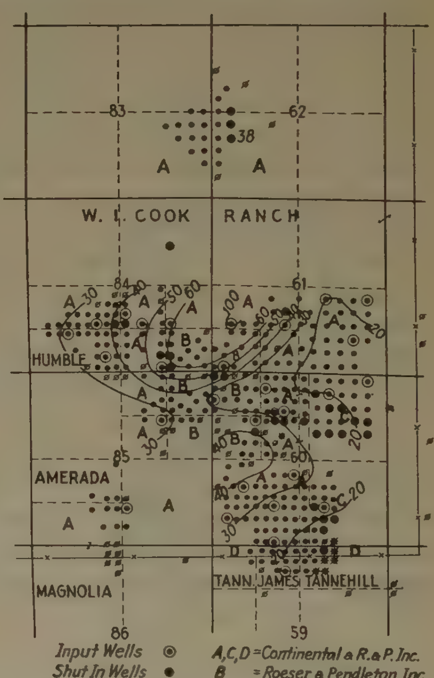

FIG. 5.—ROCK PRESSURES, COOK POOL, JAN. 1, 1931.

23, 1930, and with successive cuts is still in effect. During the first proration period the wells were pumped until the allowed production was obtained, when they were completely shut in. During the present proration the casingheads have been left opened into the gas-gathering lines at all times, because the compressors now have sufficient capacity to handle all the gas produced by the property; also, because an attempt is being made to discover whether it is possible to build up the oil saturation around the producing wells by permitting gas to flow from them without producing the oil. There have been no apparent evil effects from the first period of proration and none are anticipated from the second. However, proration has made it impossible to continue some

of the records that would have been kept in time of normal production, particularly in the measurement of oil and gas from individual wells.

Results

The progressive effects of repressuring in the Cook pool are shown by the accompanying maps and curves. The changes in rock pressures as plotted from pressures obtained at the injection wells by the method previously explained are shown by Figs. 2, 3, 4 and 5. The two curves in the upper portion of Fig. 12 are typical of the gas-oil ratio and produc-

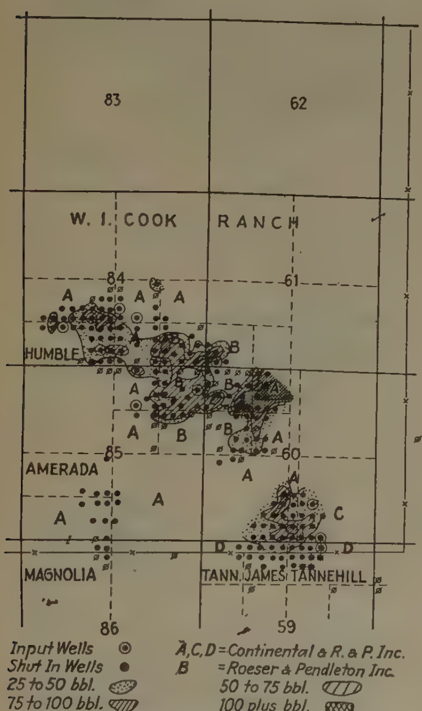

Fig. 6.—Daily oil production, Cook pool, Jan. 1, 1928.

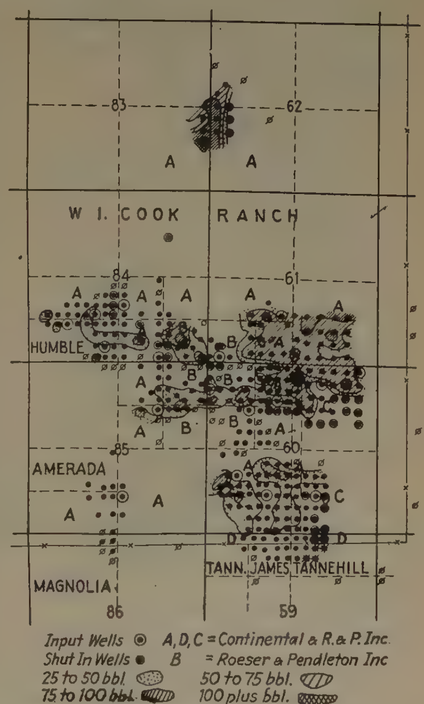

Fig. 7.—Daily oil production, Cook pool, Jan. 1, 1929.

tion of an individual well. From the individual well tests, Figs. 6, 7 and 8 have been prepared, showing the rates of oil production in various parts of the field. The influence of the injection wells is apparent. Figs. 9, 10 and 11 are gas-oil ratio maps prepared from individual well tests. These maps show clearly the spread of gas from the injection wells and also the increasing number of wells that have been entirely shut in because of their high gas-oil ratios.

The effect of continued repressuring on the physical properties of gas and oil has been the subject of some controversy. The average A.P.I. gravity of the oil produced from this pool during the past three

years, together with the volume of fractionator vapors returned through the injection wells are shown in Fig. 13. These fractionator vapors are composed mainly of propane and butane but their influence on the gravity of the oil is uncertain because of the seasonal character of all crude-oil gravity curves. Fig. 14 shows the average gasoline content of the gas taken from the producing formation, the gas-oil ratio, and the percentage of the producing gas that has been returned to the sand. The influence of proration during the year 1930 is noticeable. Fig. 15 shows rate-cumulative curves plotted on semilogarithmic paper. Curve *A* represents

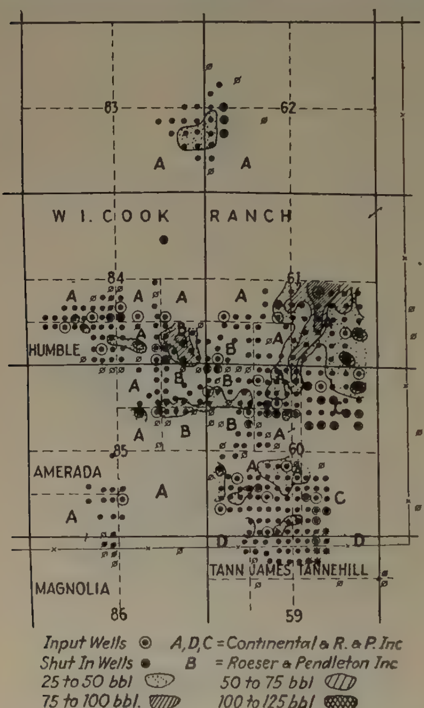

FIG. 8.—DAILY OIL PRODUCTION, COOK POOL, JAN. 1, 1930.

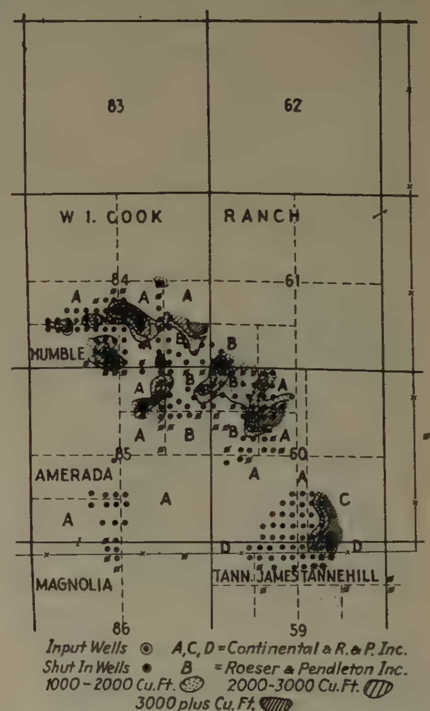

FIG. 9.—GAS-OIL RATIOS, COOK POOL, JAN. 1, 1928.

the entire repressured portion of the field. Curve *B* represents a portion of the pool in which there have been no new wells completed since Jan. 15, 1926. Periods of proration are represented on both curves by dotted lines.

Gains in ultimate recovery due to repressuring are difficult to estimate because of the uncertainty of the ultimate production under normal conditions. The usual method of projection applied to curve *B*, Fig. 15, will predict an ultimate production of 5,500,000 bbl. before the economic limit is reached. The predicted ultimate before repressuring would have been 2,750,000 bbl., a gain for repressuring of 2,750,000 bbl., or 100 per

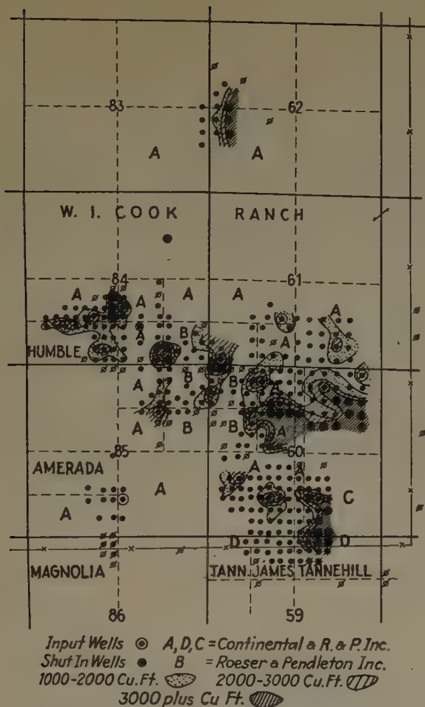

Fig. 10.—Gas-oil ratios, Cook pool, Jan. 1, 1929.

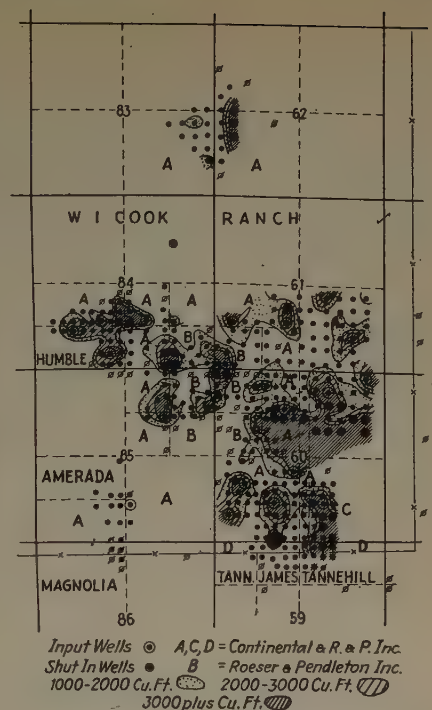

Fig. 11.—Gas-oil ratios, Cook pool, Jan. 1, 1930.

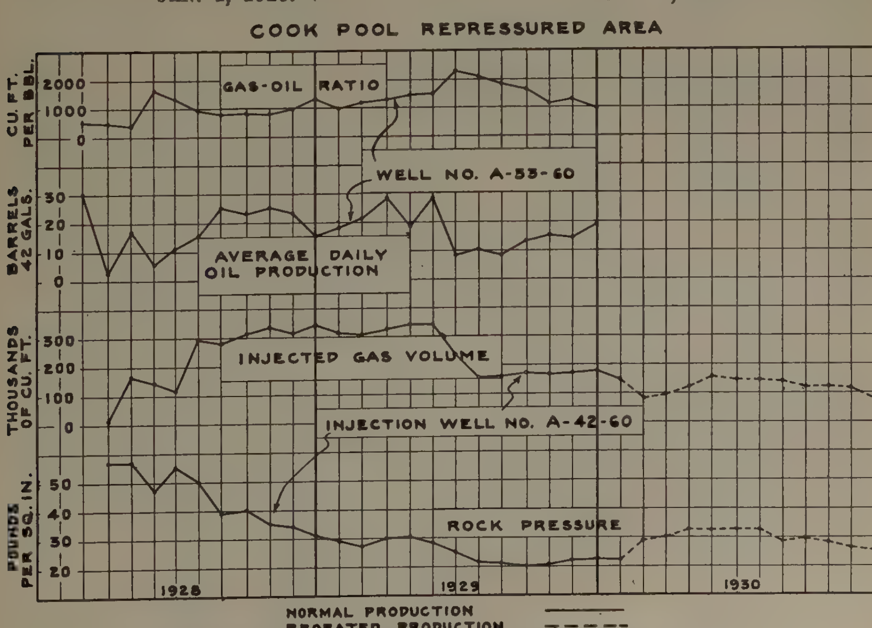

Fig. 12.—Data on Cook pool repressured area.

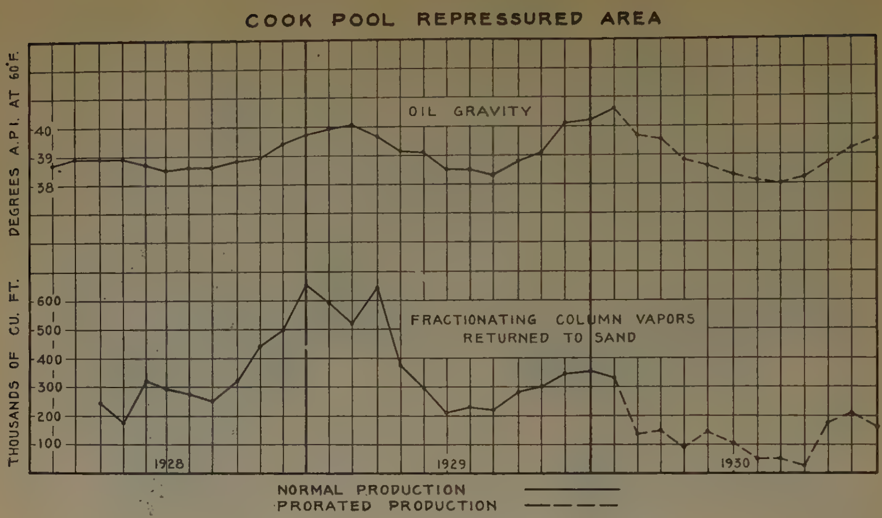

FIG. 13.—DATA ON COOK POOL REPRESSURED AREA.

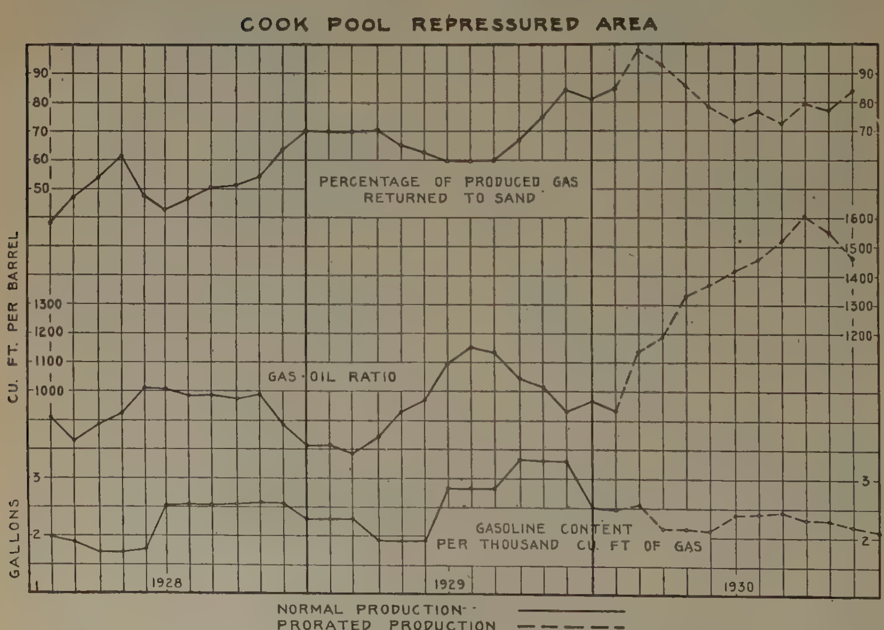

FIG. 14.—DATA ON COOK POOL REPRESSURED AREA.

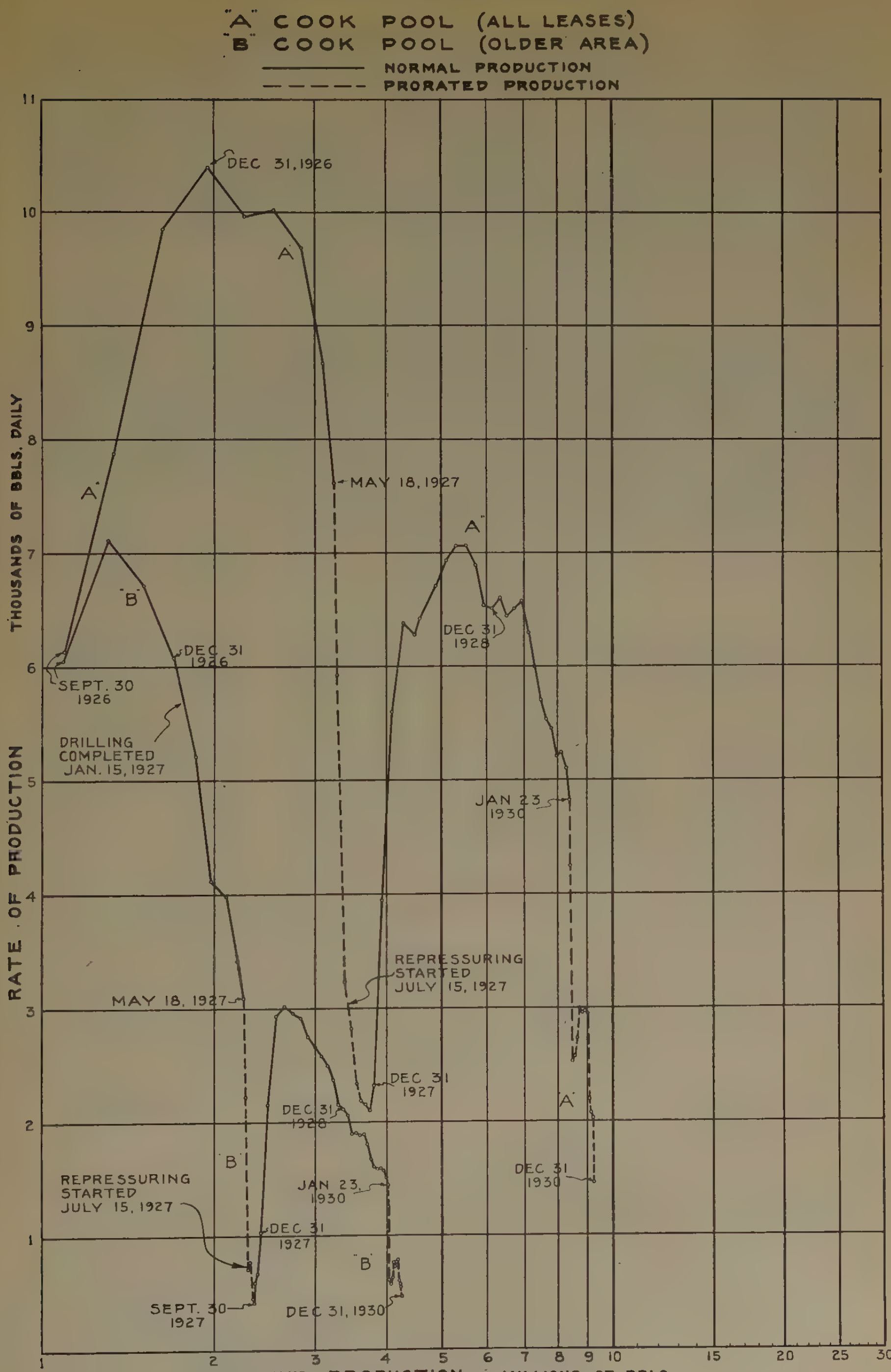

FIG. 15.—ESTIMATED GAINS IN ULTIMATE RECOVERY.

cent. Curve *A*, which includes the entire repressured portion of the field, projected to the line representing a rate of 300 bbl. per day, shows an ultimate expectation of 15,000,000 bbl. This does not include areas outside of the main body of the pool that for various reasons have not been repressured. The 1100 productive acres included in this project have produced to date 9,250,000 bbl., or 8409 bbl. per acre. The potential daily rate of production at this time is 5000 bbl. per day, the actual production because of proration is 1280 bbl. per day.

Acknowledgment

The writer wishes to acknowledge his indebtedness to Roeser & Pendleton, Inc. for the use of their records from which the data herein presented were obtained, and for permission to publish the paper. He is particularly indebted to Mr. Marshall R. Young for his helpful suggestions and encouragement and to Mr. Vaughan H. Moore for his assistance in the preparation of the various maps and curves.

Development in a Part of the Ventura Avenue Oil Field*

By Joseph Jensen,† Los Angeles, Calif. and F. W. Hertel,‡ Ventura, Calif.

(Los Angeles Meeting, October, 1930)

Many fields have been zoned by nature with shales and intermediate waters between oil zones. Limitations thus imposed have been the basis on which a field was developed. In contrast thereto, in the Ventura Avenue field, nature proved more generous. Always expecting to find such similar limitations, operators drilled deeper and deeper into the oil zone without finding any distinctive shale bodies other than the Gosnell shale and only one intermediate water, which became the point below which the final water shut-off of each well was made. Thus, on top of the structure, about 3300 ft. of oil-bearing zone has been penetrated below this intermediate water—a distance of 4000 ft. below the Gosnell shale. At first it seemed that the greater penetration in the zone, the better the well. The error of this assumption became evident as time passed. Other pressing attendant problems requiring consideration also developed.

In the spring of 1929, the Associated Oil Co., still having a large undrilled area, adopted a method for developing this land by dividing the oil formation into zones, so as to drill two classes of wells and to prepare for others, if conditions in the future justified or required such action. Wells now completed are considered as permanent completions in the zone or class for which they are drilled, and are not looked on as a ready means for deepening or accepted as a temptation for deepening to get some flush production quickly. Provision has also been made to avoid future water problems.

The most striking demonstration resulting from such work is the fact that the top of the structure is far from being the point at which the largest oil recovery is made. Wells on the flank of the structure invariably produce with lower gas-oil ratios and secure much larger oil production.

Zoning of Oil Sands

The Gosnell shale separates the upper light 50 gravity oil from the lower 30 gravity oil below. As the light oil zone is of practically no importance at present, it is not being exploited. The development pro-

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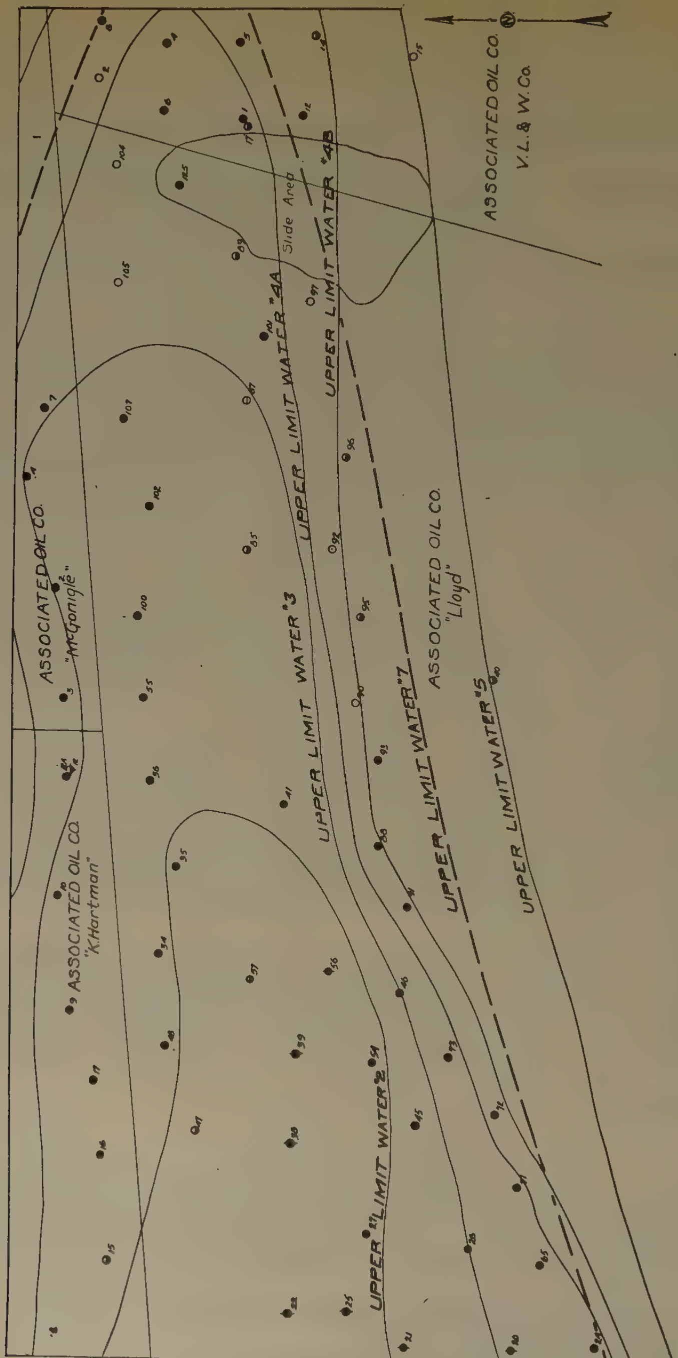

Fig. 1.—Location of edge waters, Ventura Avenue field.

gram of the Associated Oil Co. has been limited to the zoning of oil sands found below the Gosnell shale and also below the intermediate water mentioned above. At present the oil zone below the Gosnell shale has been proved 4000 ft. thick. It consists of sands and shales with no definite markers between them, except the intermediate water 670 ft. below the Gosnell shale. The differences in quantity of oil and gas production, areal extent of the zones, the location of edge waters, and the limitation of a practical drilling depth were used in differentiating the zones when this method was adopted.

Due to the intermediate water lying 670 ft. below the Gosnell shale, the final water shut-off on top of the structure above the producing oil zone has always been made at about 700 ft. below the Gosnell shale. All formation possible below that point was formerly used in each well as a source of production. Added penetration was gained by improvements in the art of drilling and by deeper prospecting. Deeper completions were also possible as the gas pressure in the field declined. One well was completed producing from 2500 ft. of zone. Though the well was free from water, it is not believed that such a well could produce nearly the maximum amount of oil that should be recovered from such a large thickness of oil zone. A study of production data of wells shows that, with very few exceptions, the production per foot of oil zone open to produce varies inversely with the amount of hole open to produce.

There are sure to be zones in which the pressures vary greatly. When a great thickness of zone is opened at the same time, oil and gas from the high-pressure sands would be dissipated into the weaker sands. Other sands whose gas was unable to dislodge the rotary mud when the well was brought in were probably sealed off so as to become high-pressure sands eventually as compared with the depleted sands resulting from the production of the well.

Edge water would be nearer the well in some sands than in others. If a great thickness of zone were taken, edge water would encroach in one sand long before the oil from other sands had been fully recovered. The edge water would thus damage the well and prevent it from producing a considerable amount of oil that otherwise it could produce from productive sands. This danger and future threatened damage from edge water was, therefore, an important factor in establishing the point to which the upper, or class 1, zone was limited.

Heavy Oil Zones

From the Gosnell shale to 670 ft. below it is found the upper heavy oil zone. This zone is separated from the zones below it by an intermediate water known as water No. 1. The upper heavy oil zone is, therefore, a natural unit by itself. It is of small areal extent compared

to the lower zones, and contains several edge-water sands. Therefore, only a small portion of the zone can be produced at one time so as to secure clean production. There was production from this zone in the early life of the field before the discovery of the deeper zones, but the zone was soon passed by after the discovery of the more prolific horizons below. Recently the Shell company has demonstrated production in this zone in a few wells near the top of the structure. The lower heavy oil zone, 680 ft. thick, lies beneath the intermediate water. No water separates the lower heavy oil zone from the underlying Lloyd zone, now proved 2650 ft. thick. The Lloyd zone has been the main source of production of the field. The development program, introduced by the Associated Oil Co. on the east end of its Lloyd lease, has been for the purpose of exploiting portions of the lower heavy oil zone, and the Lloyd zone. As heretofore explained, there are no distinctive shale bodies that make satisfactory markers in these two lower zones. Certain edge waters have proved more satisfactory as markers and as the basis on which the segregation of oil production must be made. The following edge waters have been established:

No.	Distance below Gosnell Shale, Ft.	No.	Distance below Gosnell Shale, Ft.
1	670	4-B	1800
2	1040	5	2100
3	1350	6	2600
4-A	1520	7	3000

Most of these waters have been identified on the south side of the structure. No. 6 occurs on the north side.

Fig. 1 shows the location of edge waters. The upper limits of these edge waters suggest structural contours but do not actually conform to them. The part of the field in which the development program was instituted lies below the upper limit of water No. 2.

Limit of Drilling

Experience had shown, prior to the spring of 1929, that much difficulty developed in the attempt to drill wells below 7000 to 7250 ft. Wells could be easily and safely drilled and completed to this depth, but beyond this depth a large factor of risk entered. Rather than attempt to drill beyond this safe depth in order to penetrate all of the Lloyd zone, it was decided that wells should be completed only to such depth as was assured and safe at that time. It was evident that in the future an additional oil zone would be proved and that the ability to drill to greater depths would come with improvements in drilling. The very deepest part of the oil zone which was not to be developed immediately has not yet been subject to depletion. This drilling depth limitation meant that the

penetration on the undrilled part of the Associated property would be limited to about 3200 ft. below the Gosnell shale.

Water No. 2 occurs 1040 ft. below the base of the Gosnell shale, hence approximately 2160 ft. of oil formation below water No. 2 occurs between these two limits. By dividing it approximately in half, the upper zone wells, or class 1 zone wells, would produce from 1000 ft. of formation, and the class 2 zone wells would produce from 1000 ft. of

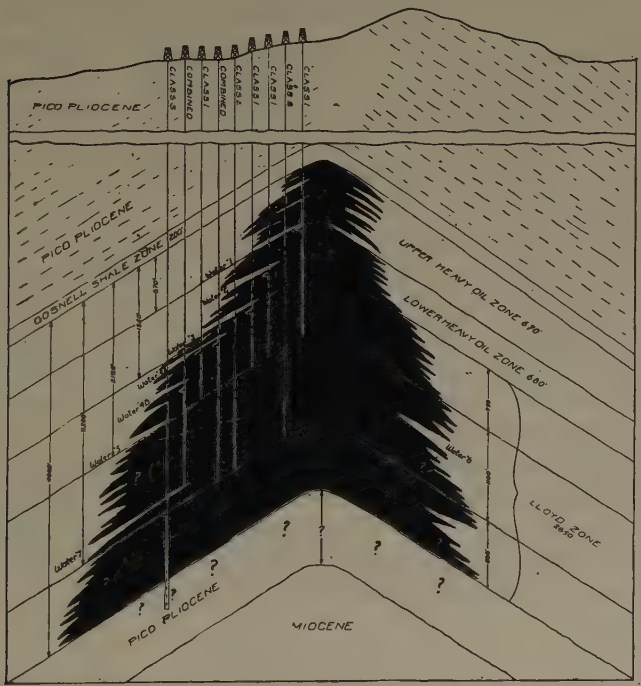

Fig. 2.—Ideal north-south cross-section through Ventura Avenue field.

formation. Since water No. 5 occurs at 2100 ft. below the base of the Gosnell shale, it was decided to make its position the dividing line between the class 1 wells and the class 2 wells. This means that as the class 1 wells are invaded in the bottom of the hole by the No. 5 water, it can be eliminated by plugging, and that the upper portion of the zone produced in the class 2 wells will be free from No. 5 water, since a combination shut-off would be made below its position. Such division in the past eighteen months has proved a very happy one.

Very recently water No. 7 has been located at 3000 ft. below the Gosnell shale on the south side of the field. Several of the class 2 wells were not drilled deep enough to reach the position of water No. 7. It is not at all improbable that this water may eventually be used as the divid-

ing line for the bottom of the class 2 wells, just as water No. 5 was used as the dividing line for the bottom of the class 1 wells.

This same method of zoning can be continued with added depth whenever the development of the deeper formations shall be necessary. The 800 ft. of proved zone and additional zone yet to be discovered makes rather certain that class 3 wells will be paying wells. It is already established that a certain number of class 3 wells can be drilled on top of the structure. The lateral extent of the lower part of the oil formation and its total thickness must still be established by further prospecting. If sufficient oil formation is found for the class 3 zone wells throughout the field and additional Pliocene oil is found, or if oil is found in the Miocene rocks below the Pliocene, the same methods of zoning can be applied for class 4 zone wells.

Fig. 2 shows the Gosnell shale, the position of the edge waters and the different classes of wells thus far drilled.

In some parts of the field it has been necessary to combine the lower portion of the class 1 zone with all or a part of the class 2 zone. This is due to the fact that at such particular location the class 1 zone was not considered of sufficient value to justify a separate well. Along property lines, due to contractual obligations, it has also been necessary to drill combined zone wells in order that the penetration of either side of the property line might be identical in offset wells.

Though the class 1 zone extends from 700 to 2100 ft. below the Gosnell shale, all class 1 wells do not produce from the entire zone. Edge water encroaches in the upper part of the zone on the flanks of the structure. As wells are drilled farther down the dip, the water strings necessarily must be set deeper to take care of the edge waters.

Spacing of Wells

One of the most striking departures from past practices in other fields in drilling these class 1 and class 2 zone wells has been the spacing of the class 2 wells at a considerable distance from the class 1 wells, instead of drilling twin wells. This reduces the danger of rotary mud damaging class 1 wells when class 2 wells are drilled and eliminates drilling through badly depleted sands. In the event of the failure of a class 2 well, it could be converted to a class 1 well, and a class 1 location in such a contingency, could be drilled as a class 2 well. Thus far this has not been necessary because the class 2 wells have all been successfully completed. As the class 2 wells have had a gas-oil ratio much lower than the class 1 wells, in the interests of conservation, more class 2 wells have been drilled in the past year than class 1 wells.

Fig. 3 shows the different types of wells planned and drilled in the eastern portion of the Associated properties in the Ventura Avenue field.

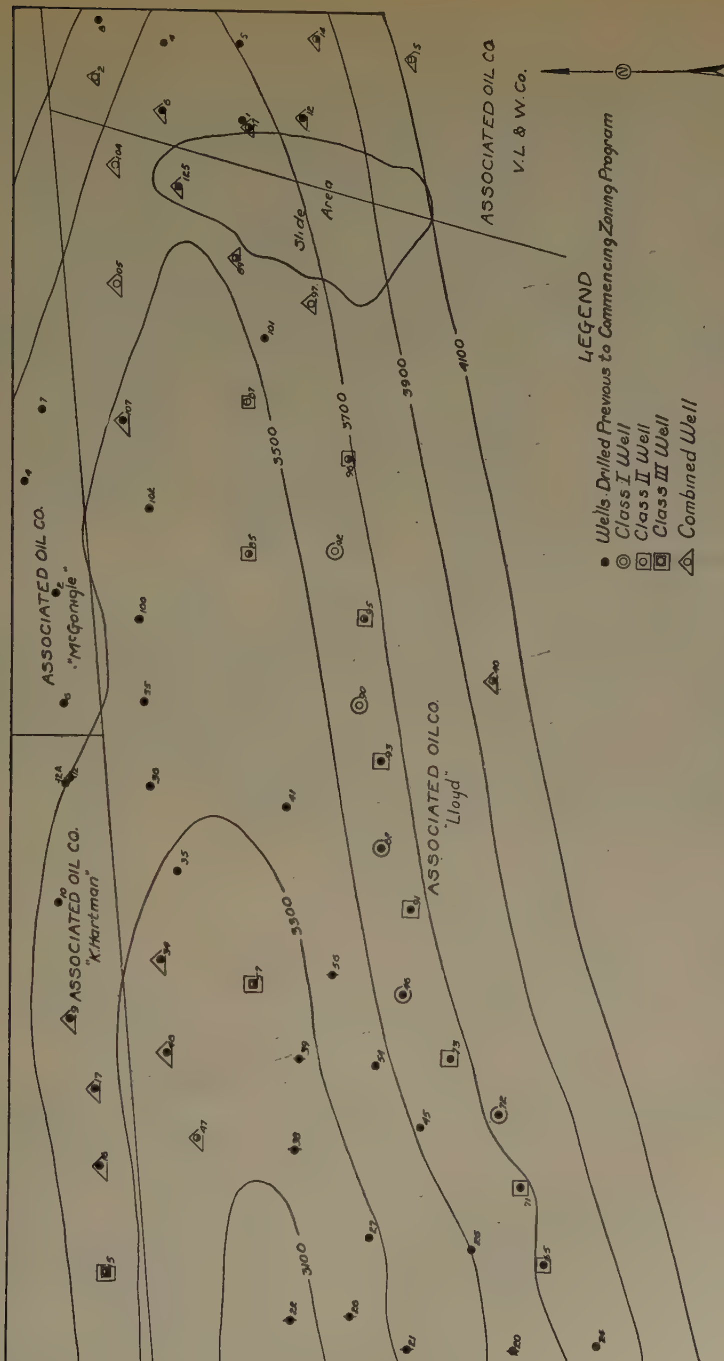

FIG. 3.—SPACING OF WELLS AND CONTOURS ON BASE OF GOSNELL SHALE.

Conclusion

From the foregoing, it is clearly evident that since ample provision is made for the development of each of these zones, there will be little temptation to abandon a productive oil horizon in order to deepen a well. Nevertheless, certain edge wells in different zones eventually may deplete their oil formation. All wells are to be completed with casing as large as possible, so that they may be used for deepening. This sort of possible future practice, however, is entirely different from the former practice in some parts of the field of deepening a producer because its production had declined so that, by such deepening, increased flush production would be secured quickly and at little present expense. Such former practice resulted in the abandonment of oil formation that would be of value for gas drive, gas-lift and pumping purposes. Since wells should produce, after flowing, as much as 100,000 to 200,000 bbl. per well, some positive action was necessary to discontinue the abandonment of such an important future resource and more properly to exploit the deeper sands existing beneath the upper formations.

The program of zoning meets all present needs as to the lower oil-bearing horizons and is so flexible that, by adjusting the spacing of wells for class 3 and class 4 zone wells, when that shall be necessary, profitable wells may be drilled and completed, even though the depth of such future wells may be 8000 and 9000 ft. The proper time for drilling such wells will be determined when the art of drilling has advanced to the point where 8000 and 9000-ft. wells can be drilled as safely and securely in this field as 7000 and 7500-ft. wells are now drilled.

Encroachment of Edge Water at Santa Fe Springs

By Donald K. Weaver,* Los Angeles, Calif.

(Los Angeles Meeting, October, 1931)

Eight different oil zones have been identified and produced at Santa Fe Springs, of which three or four are in turn divided into two or three parts. These zones, from top to bottom, are the Foix, Bell, Meyer,

Table 1.—*Data on Oil Zones*

Zone	Maximum Thickness, Ft.	Salinity, Grains per Gal.	Heads of Various Waters, Ft.	Position of Water
Foix	180	170– 220	Fairly low, about 1800	Bottom
Bell	380	270– 350	Low. 1800–1900	Intermediate and bottom
Meyer	700	450– 700 (Av. 625)	Low. 3400–3800	Intermediate and bottom
Nordstrom	525	600– 700	Low	Intermediate and bottom
Upper Buckbee	150	875	Low	Bottom
Lower Buckbee	150	1050–1175	High. 500–surface	Bottom
Upper O'Connell	175	1350–1500	Low. 4500–4000	Bottom
Middle O'Connell	150	1400–1500	Low	Bottom
Lower O'Connell	450	1500–1700	High. 800–surface	Bottom
Upper Clark	150	1550	Low. 5000	Bottom
Lower Clark or Hathaway	500	1350–1550	Low. 6000	Intermediate

Nordstrom, Buckbee, O'Connell, Clark and Hathaway, or third Clark. While there has been some difference of opinion over this nomenclature with reference to the different zones referred to as Clark, it has no particular bearing on the water problems.

Each of these oil zones has had waters of varying salinity associated with it, either within or at the bottom of the zone. Table 1 is a tabulation of the zones, their maximum thicknesses, salinity and heads of various waters. Surface waters are fresh, and of high head, giving artesian flow in some instances.

* Petroleum Engineer, The Texas Co.

FIG. 1.—WATERS OF MEYER ZONE IN 1930.

The most prolific zones of the field, to date, are the Meyer and O'Connell. Also there are more definite data on position and rates of water encroachment in these zones, on account of the large number of wells that were left to produce in them. For this reason, waters in these two zones are discussed in detail.

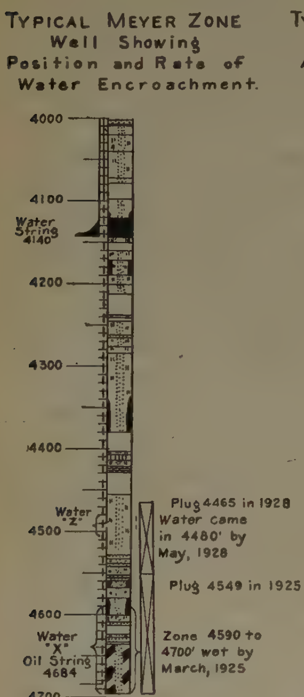

FIG. 2.—TYPICAL MEYER ZONE.

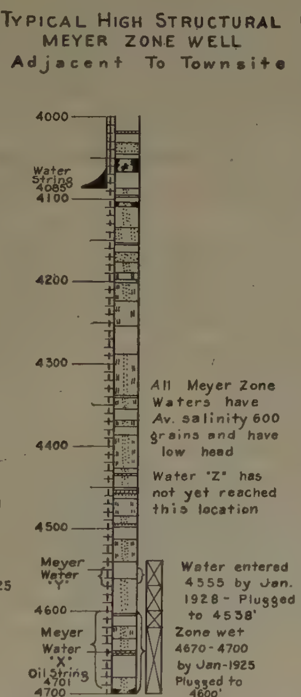

FIG. 3.—TYPICAL HIGH-STRUCTURAL MEYER ZONE WELL.

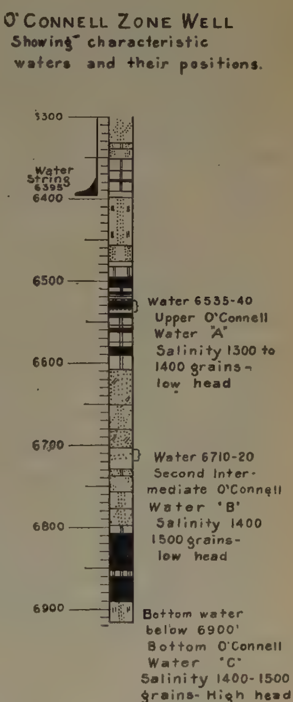

FIG. 4.—O'CONNELL ZONE WELL.

FIG. 2.—Well completed June, 1923. 1970 bbl. 34.3 gr., 0.4 per cent. cut. January, 1925, 65 bbl. oil, 125 bbl. water. Plugged to 4060 ft. and produced 20 bbl., 34.8 gr., 1.0 per cent. cut. January, 1929, well making 260 bbl. oil and 260 bbl. water, plugged to 4538 ft. and then pumped 410 bbl. 36.1 gr., 0.4 per cent. clean in 1930.

FIG. 3.—Well completed August, 1923, 3175 bbl. 34.4 gr., cut 0.1 per cent. April, 1925—Production 31 bbl. 28.8 gr., 52 per cent. cut. Plugged June, 1925, to 4549 ft. Well then made 329 bbl. 34.4 gr., 6.0 per cent. cut. May, 1928, well pumped 105 bbl. net oil, cut 54 per cent., plugged to 4465 ft. on June 12, 1928—well then pumped 125 bbl. 35.4 gr., 2.8 per cent. Well clean August, 1930.

MEYER ZONE WATERS

The Meyer zone has the greatest areal extent of any of the Santa Fe oil zones. It was originally productive 700 ft. structurally below the top of the dome. Greatest penetration naturally was possible on the top of the structure, and wells so located were able to produce from below a bottom of 4700 ft. Between 1923 and 1925, salt water gradually encroached in the bottom 100 ft., necessitating plugging the wells to

about 4600 ft. This water has continued its encroachment until only the highest portion of the field is still free from it. The area covered by this water is shown in Fig. 1. (The water is also shown as X on Fig. 2.)

In the closely drilled, and consequently heavily drained, town-site area, another water, shown on Fig. 3 as water Y, has come in at about 4555 to 4560 ft. This water has been identified only in the town site and seems to be more or less confined to this location.

Water Z, shown on Fig. 3 at about 4480 ft., has come in from the northwest, and is rapidly taking a toll of clean wells in its path. On the Meyer zone map (Fig. 1) the limits of this water Z in 1927 are shown, together with the position and amount of encroachment up to the middle of 1930.

All waters found in the Meyer zone are of low head, and have a salinity of from 450 to 675 gr. per U. S. gallon, with the average about 625 gr. From the constant higher occurrence of waters in the Meyer zone, a vertical migration of water might be suspected. However, this zone is composed of alternations of tough brown shale and fine-grained oil sand; the shale streaks are impervious and the waters undoubtedly are different encroaching edge waters coming in along the sands, which either were least saturated or gave up their oil most readily.

Some successful repair work has been possible on these low head waters. Figs. 2 and 3 show the history of such work. In almost every case the water has been successfully plugged off. This work is most satisfactory for, while a drop in production of gross fluid results from the plugging, only the production of water is lost and the average well so plugged shows an increase of production of net oil of from 50 to 150 barrels.

There is no evidence that these encroaching waters are acting as a water drive to increase production in the top structure wells not as yet affected. Some increase in production often results as lower wells are taken off production because they have got wet, but this is probably due only to there being less drainage from the sand.

O'Connell Zone Waters

A persistent water, shown on Fig. 5, is water A, which occurs on the bottom of the upper O'Connell zone, about 150 ft. below the top of the upper O'Connell sand. Salt content of this water varies from 1350 to 1500 gr. per U. S. gallon. The original limits of this water are shown on Fig. 5, together with the amount of encroachment that occurred during the twelve months following the discovery of the zone. This water has a low head with average fluid level from 4000 to 4500 ft. from the surface. Often this water has been produced with the entire O'Connell zone in order to obtain the flush oil production from the middle and lower O'Connell zones shown in detail in Fig. 4.

Another low head water (*B*, Fig. 5) of about the same salinity as the upper water occurs at the bottom of the middle O'Connell zone. This water occurs about 320 ft. below the top of the upper Q'Connell sand, and has entered wells at a level of 6700 to 6720 ft. Its original limits and encroachment after twelve months are shown on Fig. 5, the encroachment having been indicated only where definite information as to its position exists.

These two O'Connell zone waters are really intermediate waters and have not been plugged off in the field in such a way as to make possible the producing of a well free from water above and below the water

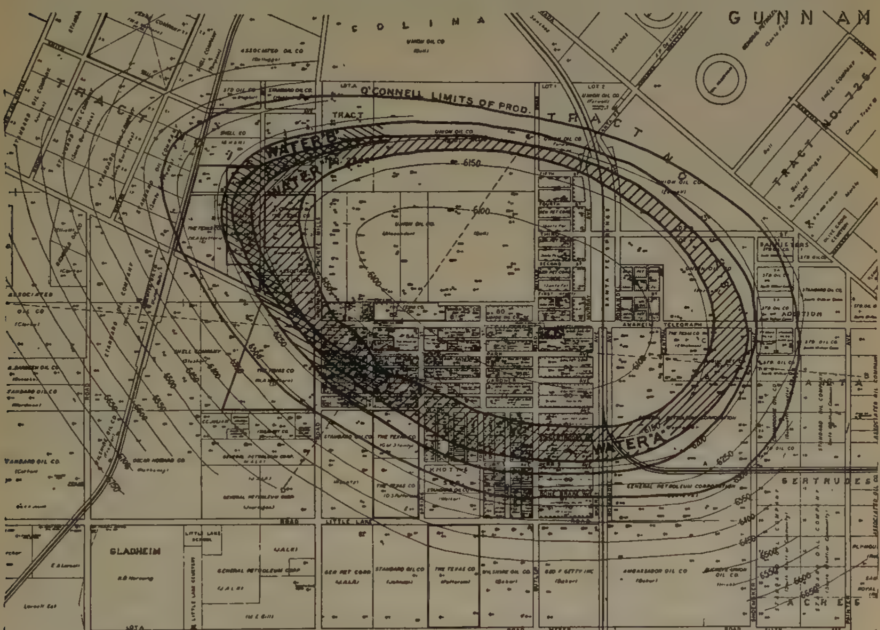

Fig. 5.—Waters of O'Connell zone.

strata. In practically all successful plugging jobs in the O'Connell zone, the middle and lower portions of the zone have been sacrificed to produce clean oil from the top 100 to 125 ft. of the upper O'Connell.

In the original development of the O'Connell zone, on the west plunge of Santa Fe Springs wells that encountered the top of the sand below 6380 ft. found water *A* present while wells higher on structure were clean. On the east plunge, water *A* was found 50 ft. structurally higher, and wells on this end of the field showed nowhere near the ultimate recovery of oil from the zone. One well on the west end, which found water *A*, came in for 6600 bbl. of fluid, with a cut of 30 per cent. This well produced 325,000 bbl. of net oil before sanding up, and at that time the cut did not exceed 45 per cent.

Bottom water in the O'Connell zone, except on the top of the structure, occurs at about 6900 ft. This water has a high head and often has an artesian flow. The salinity is slightly higher than the intermediate waters, having a limit of 1700 gr. per gallon. Where this water exists, it completely eliminates oil from the well, and it is very hard to plug off on account of the high head.

An O'Connell zone well which had been clean originally and produced over one million barrels of oil was deepened below 6900 ft. in the hope of including some additional clean oil zone. Although the cores. showed a cut in ether, the sands did not look well saturated. When the well was tested with this new zone open, the well showed 100 per cent. salt water, which stood 200 ft. from the surface. This is the high head O'Connell water *C* referred to in Fig. 4.

The lower part of the O'Connell zone has the greatest areal extent and is probably the most prolific. It seems probable that the high head water is driving the oil up structure in such manner that top-structure wells will enjoy a much greater recovery of oil from this part of the zone. Future production figures and curves, however, will be necessary to demonstrate this water drive.

DISCUSSION

(*John F. Dodge presiding*)

S. C. Herold,* Los Angeles, Calif. (written discussion).—This subject of energy with respect to gas and water within the reservoir is an interesting one. In California we have first a period of time wherein gas expansion is causing production, a so-called period of flush production, and thereafter we have a period wherein water is the sole agent that is driving oil to the well. The latter period we describe as that of settled production.

As a matter of fact, the period of gas expansion lasted eight months for the Milham well No. 1 at Kettleman Hills. The same period lasted three years, as I remember, for some 125 wells at Long Beach, and again approximately three years at Dominguez.

When the change is made from gas expansion to water-drive there is a sudden break in the direction followed by the production curve. Each part of this curve can be said to be a straight line, but of course we know from practice that it does not always appear exactly straight. In an ideal reservoir system each would be straight. Practical curves are not straight because of changes in the size or physical state of the orifice controlling the rate of production. Even so, the general analytical principles of production hold.

One of the most difficult matters to accept, it seems, is the fact that during the first period the gas is expanding and actually doing work in driving oil to the bottom of the well whereas in the second period the gas, although expanding, is doing no such work. Gas can expand without the performance of work. Whether it does work or not depends upon whether nature, or we ourselves, cause it to do such work. This fact has long been known by engineers who have studied thermodynamics.

We may say that during the flush period the gas is active, and that during the settled period the gas is passive. The gas-oil ratio during the former period is con-

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* Consulting Geologist and Engineer.

siderably higher than it is during the latter period. The gas, wherever it may be—within the producing zone itself, within irregularities at the roof of the zone, or within enclosures like lenses where the formation pinches out as it extends up the structure—expands and pushes oil in the flush period, coincident with the formation of a spout-shaped pressure gradient. Thereafter any remaining gas merely expands to accommodate itself to a decreased pressure as the hole is approached, if it is approaching such hole, or to a decreased pressure exerted by the head of water in the formation if it is remaining in irregularities or enclosures.

In California fields water encroachment is not an unnecessary evil, but a very necessary one. We must have encroachment or we shall not get the oil. Water is the source of the energy here, and even that energy of the gas in the flush period is derived from the water. In speaking thus of encroachment we refer, of course, to the reservoir at large. If there is division of property at the surface over the reservoir, each owner may hope that the necessary encroachment takes place upon the neighbor's property and not upon his own.

We sometimes inject gas in reservoirs to hold back the water. Oil is displaced on the crest. It will stay there if crest wells are closed. It is inactive while there unless we make certain changes in the conditions of production from the reservoir; for instance, unless we open a well that was not open before, or open one more widely than before. In a change of this sort we allow the gas to become active once more for a brief period of time. But as long as the gas remains quiet it does no work of any sort. Stored gas adds no energy to a reservoir in California fields. This does not mean that during injection we do not have increased production at neighboring wells by letting the gas out as rapidly as we put it in. Storage and injection are processes of a different sort.

This entire question of water and gas seems to be difficult. I have made certain interpretations of the curves as they appear. I do not say that I am 100 per cent. correct. There are many modifications to be made yet. So far as I have gone, the general principles seem to be fulfilled satisfactorily. I am still looking for some exceptions and some phenomena that cannot be explained satisfactorily.

Water Problems of the McKittrick Oil Field*

By Joseph Jensen,† Los Angeles, Calif. and J. B. Stevens,‡ Fellows, Calif.

(Los Angeles Meeting, October, 1930)

The history of the normal oil field is supposed to show an oil graph starting high in flush production, descending more or less steeply into the curve of settled production and dropping gradually to the vanishing point of economical operation. Together with this, somewhere in the early history of the field, there appears from a vanishing point a graph showing the production of water. During the period of settled production this graph rises higher and, toward the close, unless extensive work is done in the line of correction, rises far above the oil graph to the point at which the cost of operation terminates profitable pumping. Fields that start out with a high relative content of water are generally very short-lived. Fields that never develop a water problem are exceedingly rare.

The McKittrick oil field, Kern County, California, with 840 acres of proved ground, 300 wells and a present recovery per acre of 94,598 bbl. from 1898 to Aug. 1, 1930, presents a study which is an apparent reversal of the outlined normal history. Though the history of the field now covers over 30 years of operation, it is still too early and the conditions too unique to project the graph of production to completion. The present conditions and directions of change are most interesting, in that the curve of oil production is remarkably flat and the curve of water invasion, after reaching an appalling height, has shown a definite reversal and a continued decline for 10 years.

Early drilling in the McKittrick field was in or prior to 1898. Development continued steadily to 1918 when the present limitations of the field were determined. Shut-offs, according to accepted practice of the time, were made by driving the shoe into a shale stratum or into a tamped-in bridge of sand, rosin and clay.

Records of early days speak of three waters: (1) surface water which was fresh; (2) an intermediate sulfur water, encountered below the top oil or tar sand; (3) bottom salt water. In different portions of the field any one of these waters let into a well by faulty completion might require immediate correction to obtain satisfactory production. In many wells,

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however, the effect of faulty completion was delayed by high initial oil production and became evident only as the well approached the stage of settled production.

As the McKittrick field is in a very arid portion of the San Joaquin Valley, the fresh water was undoubtedly supplied from Santa Maria Basin, about one mile southwest of the oil field and at about 500 ft. higher elevation. This basin, 2 by 4 miles in extent, gathered and held the run-off of approximately 15 square miles of the adjacent Temblor Range. The lower lip of the valley spilled its overflow in a large spring which, flowing down a canyon, crossed diagonally the northwest, widest and most productive portion of the oil field, with abundant opportunity for this seepage water to enter the open porous measures overlying the oil sands.

The intermediate water over a longer, more indirect route, undoubtedly came from some similar source. This water never developed the head or volume of either of the other two waters.

Bottom water, drilled into in the lower portion of the field, would flow at a rate from 500 to 1000 bbl. daily. In other portions of the field it was a high head water of apparently inexhaustible volume. This head may have, in part, been due to associated gas in the oil zone and the water sand. With the loss of gas, the head was bound to change.

Water-bearing Strata Not Continuous

The McKittrick oil field structurally is an accumulation largely, if not entirely, against overthrust faulting in which thrusting from the southwest has caused older measures, across a shear zone, to override younger strata. In places, upturned Paso Robles and Etchegoin measures of the Pliocene are exposed in vertical position. In other portions of the field the structure is masked by erosion or appears as an overturned fold. In still other portions of the field the overthrust is evident only in the well logs, a considerable thickness of brown shale of the Miocene being drilled through before the younger measures of the Pliocene, which contained the oil zone, are encountered. A complicated water problem was to be therefore expected. A study of the field from logs and cross-sections, fluid levels and points of water invasion, shows that there is no one water-bearing stratum that is continuous. While the field is structurally a unit, the occurrence of the water was more or less local, with different areas presenting apparently unrelated and independent water problems.

As the production of the field fell away from the initial flush production, a serious water problem was evident to all operators, and as the water-oil ratio increased, more and more heroic measures were taken to handle the fluid volume and keep the water table down to where certain

wells in the field were able to produce at all. During this period of operation, compressors were installed and many wells blown by air. For a period of five years the field was producing not less than one million barrels of water per month.

Some time during this period of excessive water production a peak was passed, the fluid volume began to decline and the water table to sag away. After some years of operation there was not enough water in the wells or sufficient submergence to make compressor operation practicable, and they were discontinued. Then followed a period of rapid pumping which carried the descending curve of fluid volume across another period of its history. This in turn was followed by slowing down the pumping action and there are now being installed in the field numerous slow-motion pumping units of four, five and six strokes per minute.

In a number of the wells that were once heavy water producers, water almost entirely disappeared and throughout the water-producing area of the field fluid levels have dropped over 200 ft. Some few wells with bad casing can no longer be pumped as the fluid levels have dropped below the bad pipe.

Explanation of Variation in Water Invasion

The explanation of this reversal in the graph of water invasion is in part simple, because so unique, and in part difficult, because determined by factors largely unknown. The simple part of the explanation is in the disappearance of the fresh and sulfur water from the wells.

As the Santa Maria Valley held the only substantial fresh water suitable for domestic purposes in the southwest foothills, it was early entered by the Chanslor-Canfield Midway Oil Co., Associated Oil Co. and the Pacific Oil Co. for their fresh water supply. In a few years, the spring at the lower lip of the valley ceased to flow, then shallow wells had to be deepened and more wells drilled to obtain a satisfactory supply. At the present time, good producers have to be 500 ft. deep for sufficient submergence for heavy production. When pumping is stopped, the water table will rise to 110 ft. from the surface. A comparison of water production and rainfall figures shows that the basin is slowly but surely being emptied. It was natural that with the supply of surface seepage removed, the top waters, fresh and sulfur, would become depleted. This has taken place. Hence the reversal in the water curve.

Just why the bottom salt water should become depleted is not clear. It is possible that only a certain head has been removed, this covering the salt water fluid table in the wells and that at somewhere near its present depth the volume would remain unaffected and the table unchanged over a long period of operation. It is possible that the faulting referred

to above has in some way limited the area of connate water connected with the producing area, and that in time it may be completely exhausted. It is also possible that its rate of advance is slow, or its head has been overbalanced by the rate of production and would recover if operations were discontinued.

The fact remains that the curve of water production, after starting far below that of the oil and ascending far above it, has subscribed an arch; is now well over on the descent and is again about to cross the oil curve on its way apparently to disappearance.

Chronological Order of Water Invasions

To present chronologically the subject matter of the text, the status of water invasion of the McKittrick field for the years 1915, 1921, 1923 and 1930 are cited. In 1915 the field after approximately 15 years of production was near the close of its development period. This is the first year in which reliable data were available for any considerable portion of the field.

In 1915 the heavily watered area was small and in isolated spots. The area of very small water content was also small. As a whole, the field was neither dry nor drowned.

In 1921, six years later, there was a pronounced change. The large water-producing wells had taken the whole northeast (deeper) portion of the field, and the area of light water production was more heavily watered. Between 1915 and 1921 there was pronounced water invasion.

The year 1923 showed a change in the other direction. The heavily watered area was more restricted. While the whole field showed watered areas, less water was produced.

Following a lapse of seven years from 1923, the year 1930 shows striking changes. There is no large continuous area of heavy water production. Conditions are similar to those of 1915, fifteen years before. Throughout the whole water-producing area of the field the water volume has declined. This is confirmed, as shown above, by operating conditions in the field. Compressors have all disappeared, not because they accelerated invasion, but because of insufficient submergence. Only a few long-stroke, rapid pumps are left in the remaining badly watered spots. Fluid levels have dropped over 200 feet.

The future of the McKittrick field will depend solely on the behavior of the bottom and edge salt water. From now on the field should take its place and perform in the normal manner of an oil field with all top and upper waters eliminated.

Effect of Edge Water on the Recovery of Oil

By H. H. Wright,* Tulsa, Okla.

(Tulsa Meeting, and Los Angeles Meeting, October, 1930)

In many fields edge water is one of the most important factors governing the production of oil. Possibly this fact is not appreciated by many producers except in so far as it may bring about a loss in production from wells drilled on the flanks of structures. In the light of artificial flooding as practiced in New York and Pennsylvania, and of the beneficial effect of natural water-flooding on many wells and leases in the Mid-Continent and elsewhere, it seems reasonable to suppose that very few phases of the petroleum industry hold greater promise for future benefit than the study and control of the natural water drive.

Rate of Water Encroachment

The rate of movement of water in artificially flooded areas has been referred to as so many feet per unit of time, usually from an injection well toward surrounding producing wells. This definition is vague when used in reference to the movement of natural edge water, inasmuch as such factors as sand thickness, steepness of dip and horizontal extent are not considered. In the ultimate analysis, only the vertical component of movement affects the production of oil in the natural drive, and in order to define the rate of water encroachment more exactly, such a term as acre-feet per unit time might be used. Thus, where one well is located to each 10 acres a vertical movement of 5 ft. in the water level in a year would be defined as an encroachment of 50 acre-feet per year, and where one well is located to each 20 acres, as 100 acre-feet per year. Such a definition as this is entirely arbitrary, but it takes into consideration to a certain extent the influence of well spacing, and consequent sand drainage, on the rate of water movement.

The rate of movement is considered to be an important function of water encroachment, for it is believed that the efficiency of recovery by natural water flood depends a good deal upon the rate of movement. In general, rapid encroachment is thought to effect a poor recovery because of the differential in favor of the movement of water through a sand body and the consequent tendency to trap oil in the sand. Slow movement, on the contrary, is thought to bring about a partial displace-

* Petroleum Engineer, Gypsy Oil Co.

ment of oil from the sand pores and to move oil up the dip with little by-passing. This effect may be illustrated by the well sustained production of some edge wells, where only a small amount of water is produced over a considerable period of time. It may be contrasted to wells having a more or less normal decline up to a certain point, after which the rate of oil production is suddenly increased and maintained over a short period with a subsequent extremely rapid decline in oil production and increase in water. Wells of the latter type appear to be more particularly those from which oil has been produced at a rapid rate, such as air-gas lift wells, or those in small pools where the structure has been completely drilled in a short time. However, this effect has been observed in wells not of either of these two types, indicating that other factors influence the rate of travel. This may introduce the observation that wells evidence a capacity for water production.

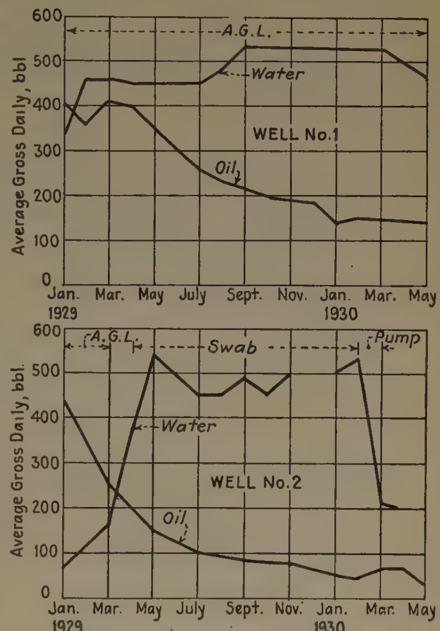

FIG. 1.—CAPACITY FOR WATER PRODUCTION OF TWO ADJACENT WELLS IN EARLSBORO FIELD

Production data on two adjacent wells in the Earlsboro field, having similar structural positions, illustrate the apparent capacity for water production. These data are shown graphically in Fig. 1, and appear to indicate that both wells reached their capacity for water production at about 530 bbl. daily. It appears significant that while well No. 1 reached a maximum fluid production in excess of 800 bbl. daily in the first part of 1929, it produced a maximum amount of 530 bbl. of water when the total fluid production was as low as 670 bbl. daily. Well No. 2 produced a maximum of 540 bbl. of water daily when the oil production was 150 bbl. The decrease in oil production from 150 to 45 bbl. apparently did not increase the capacity for water production, for in February, 1930, the well produced 530 bbl. of water and 45 bbl. of oil. The evidence from these two wells indicates that the maximum rate of water movement through the sand had been reached for the existing conditions of water head and sand characteristics related to these wells, particularly in view of the fact that well 1 has 26 ft. of sand penetration as compared with 14 in well 2.

That the rate of water encroachment in different fields varies is illustrated in the Greater Seminole area, where water encroachment has been more rapid in some pools than in others. In the Seminole City pool, 13 representative wells had an average elapsed time of 618 days between completion and the day that water appeared. In the Mission pool the average time was 272 days for eight representative wells. The recoveries from these pools will serve as examples of the effect of natural water-flooding. All evidence tends to indicate that three factors mainly control rate of water movement. These are: (1) pressure head on the water; (2) sand permeability, or resistance to flow; (3) rate of depletion of oil and gas content.

Effect of Water Encroachment

It is customary in production-control work to make use of type decline curves which represent the average performance of a number of wells. Often such curves are influenced by two or more distinct types of production, as well as by several production methods. It is believed that more accurate comparisons could be made by classifying production and preparing type declines for the various classes. Ordinarily this is not done to such an extent as to allow of close comparisons.

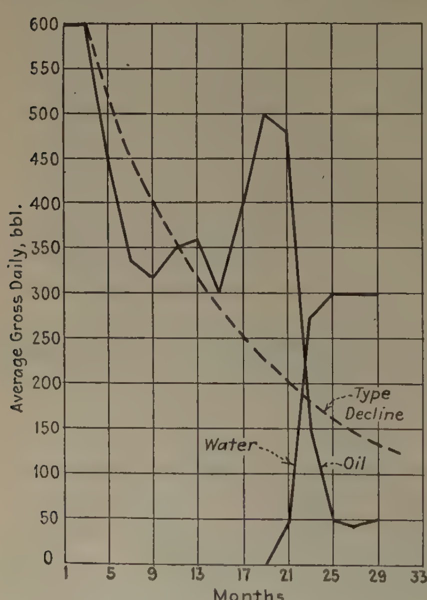

Fig. 2.—Seminole well influenced by rapid water encroachment.

The type decline curves shown in Figs. 2 to 7, inclusive, represent the average performance of 20 or more normal wells under certain uniform methods of operation. These curves include wells influenced by varying degrees and rates of water encroachment, and represent the average expectancy of wells in the district from which they were compiled.

Fig. 2 compares the decline curve of a Wilcox sand well in Seminole with the average curve for Seminole Wilcox sand wells. The production of this well has been influenced by a rapid rate of water encroachment. Fig. 3 compares the decline of a well influenced by a slower rate of encroachment. Both wells were completed at approximately the same time, and obviously the more rapid rate of water movement has returned the

greatest amount of oil to date. However, the slower encroachment will yield considerably more oil ultimately, in spite of the fact that the well with the slower water movement had the smaller initial production and had a rapid decline during its flush stage. It may be inferred from these examples that a controlled rate of water movement might have promoted more efficient recoveries in the well shown in Fig. 2, by an increased rate of movement, and in that on Fig. 3 by a retarded rate.

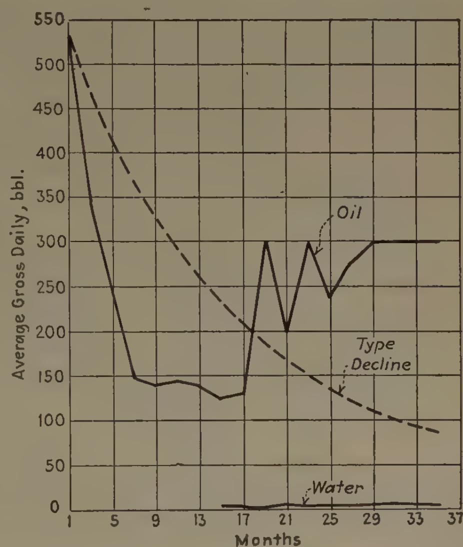

FIG. 3.—SEMINOLE WELL INFLUENCED BY SLOW WATER ENCROACHMENT.

Fig. 4 shows a Wilcox well in the same area as the wells shown in Figs. 2 and 3. This well serves as an example of flush production but slightly influenced, if at all, by water head. Slowly encroaching water is maintaining a small daily production over a long period of time. Evidently in a well of this type the depletion of oil and gas originally in the sand has been at a rate in excess of the ability of the water to travel through the sand; that is, gas expansion is assumed to be the direct cause of the movement of oil into the well. Were this curve characteristic of Seminole production, more particularly without the slow water encroachment and sand flooding, Seminole would long since have been history.

Fig. 5 is a decline curve of a well in the Cromwell pool. It shows a well sustained rate of production, and is an example of the beneficial effect of a slow rate of water encroachment. Although this well has made water in small amounts only, other wells surrounding it have produced considerably more, about one-half of the 80-acre lease having been on the edge of the pool originally. It is interesting to note that eight months ago the production of water in this well stopped, and that no water has been produced since. It is thought that this behavior is the result of a change made about a year ago from individual pumping units to pumping by central power, whereby all wells on the lease excepting this one, which is still produced with an individual unit, are produced at a slower rate. The approximate recovery from this well has been 218,000 bbl., whereas under the type decline recovery would have been about 170,000 bbl. The average recovery per acre for the lease is slightly over 8500 bbl., while this particular well has produced 21,800 bbl. per acre.

The decline curves of two wells in the Burbank field, the recoveries from which are influenced by water-flooding, are shown in Figs. 6 and 7. These two wells were completed at the same time, with initial productions of 840 and 1440 bbl. Individual well gages are not available for the period between completion and the seventh month's production. However, the well in Fig. 6 serves as an example of the benefit of natural water-flooding. The recovery from this well from an average monthly production of 49 bbl. daily in the seventh month to the seventy-fourth month

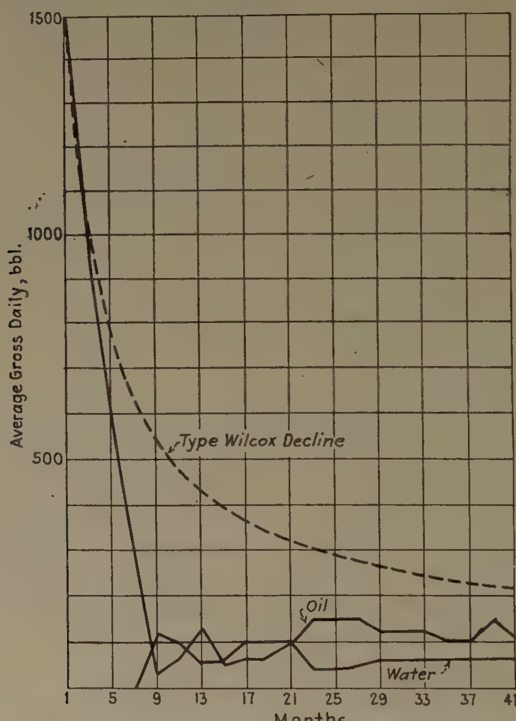

FIG. 4.—SEMINOLE WELL SLIGHTLY INFLUENCED BY WATER ENCROACHMENT.

does not quite equal the average recovery of wells higher on the structure, where gas is the predominating expelling force, but this well gives promise of exceeding the recovery of the higher wells in the near future. The comparative recoveries of this well and the average of wells on top of the structure for the period indicated are approximately 34,400 and 36,400 bbl., respectively.

Fig. 7 is an example of a much better recovery due to water-flooding. Recovery from this well for the period from the seventh to the seventy-third month, inclusive, has been about 80,700 bbl. as compared to the average recovery of approximately 36,400 bbl. for wells not benefited by water-flooding. It may appear from Fig. 7 that the average decline

curve should have been tacked on at 69 bbl., which represents the largest average daily production for any month beginning with the seventh.

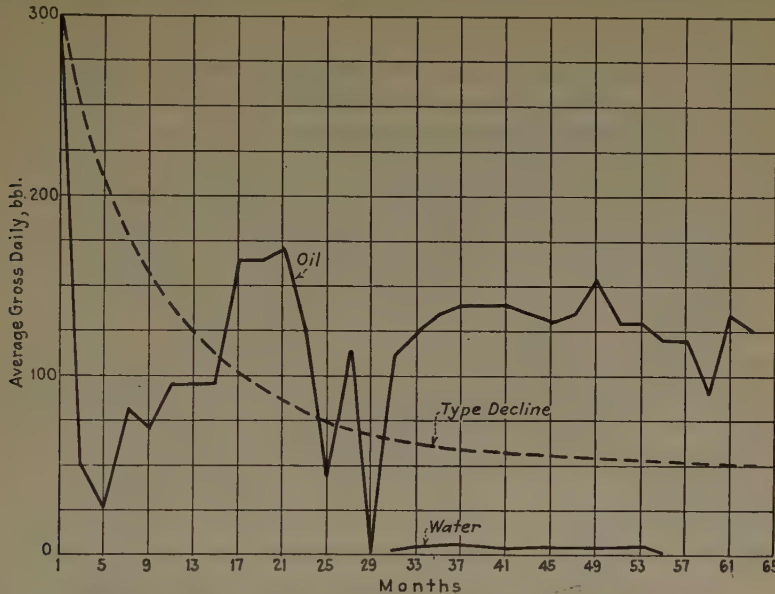

FIG. 5.—CROMWELL WELL UNDER INFLUENCE OF NATURAL EDGE-WATER FLOODING.

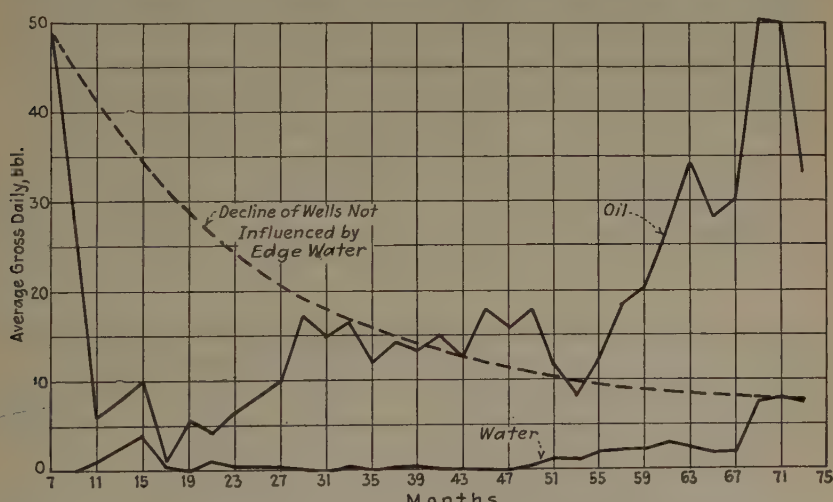

FIG. 6.—BURBANK WELL; INITIAL PRODUCTION, 840 BBL.; EFFECT OF NATURAL WATER FLOOD.

As it happened, the wells shown in Figs. 6 and 7 each had an average daily production of 49 bbl. for the first month for which individual gages are available. Both wells at that time were under the influence of water

drive or flooding, and, consequently, both should be compared to the average decline curve for wells on top of the structure beginning with the first month. If the average curve had been tacked on at 69 bbl. the recoveries would have varied little from those given, and the principle illustrated would have remained unchanged. Actually, the recoveries from 69 bbl. average production on would be approximately 71,500 bbl. for the well and 42,000 under the average curve.

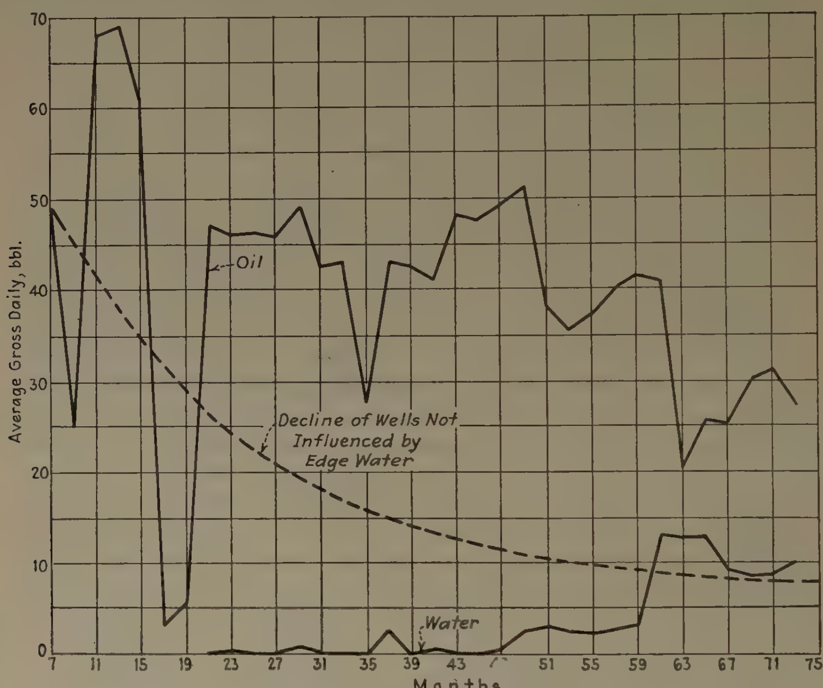

FIG. 7.—BURBANK WELL; INITIAL PRODUCTION, 1440 BBL.; EFFECT OF NATURAL WATER FLOOD.

METHODS BY WHICH WATER-FLOODING CAN BE MADE MORE EFFECTIVE

It is thought that the efficiency of natural edge-water flooding is a function of the rate of encroachment; but it does not follow that the rate most effective in one locality will return a high recovery in another. The most effective rate of natural water movement must depend upon sand conditions, nature of oil and water content, structure, water head, well spacing, production methods, rate, method and sequence of drilling, and possibly other factors. Of the factors enumerated, well spacing, production methods, and rate, method and sequence of drilling can be controlled. Earlier in this paper, it was shown that the recovery from parts of several oil fields in Oklahoma is influenced by natural water-flooding.

It is probable that the energy in natural edge water is susceptible to efficient control, as is the energy of gas expansion. It is conceded that it will be more difficult to control than gas, but the possibilities of making the greatest use of natural water-flooding give promise of large returns, particularly in such fields as Seminole, where the recovery of oil appears to be greatly influenced by water, even in the flush stage of production.

The most suitable method of drilling, spacing and producing wells so as to make most use of natural water-flooding can only be made effective under some plan whereby the pool or field is developed and operated as a unit. The recovery from natural water-flooding is of sufficient magnitude to justify serious consideration of its employment to the fullest extent.

Conclusions

1. The recovery of oil from many fields is influenced by natural water-flooding, and in many fields, or parts of fields, this natural flooding has been one of the main factors contributing to efficient recovery.

2. The rate of water movement greatly influences the effectiveness of natural water-flooding.

3. The factors largely governing the rate of movement are: Hydrostatic head of the water, permeability of the sand body and rate of removal of oil and gas from the sand.

4. The most effective rate of movement must be governed by sand conditions, nature of oil and water content, structure, water head, well spacing, production methods, and rate, method and sequence of drilling.

5. At least three factors governing the effectiveness of natural water-flooding can be controlled. They are: well spacing, production methods, and rate, method and sequence of drilling.

6. The rate of edge-water encroachment can be controlled, to some extent at least, by proper well spacing, producing methods, and rate, method and sequence of well drilling, if consideration is given these factors in the development and operation as a unit of a structure bearing oil and gas.

7. The effectiveness of recovery by natural water-flooding is of sufficient consequence to become a strong argument in favor of making an operating unit of the whole pool or structure rather than of the individually owned and operated lease.

DISCUSSION*

J. Chalmers,† Bartlesville, Okla.—Mr. Wright has presented some interesting data on edge-water encroachment and its effect upon the recovery of oil. An operator should by all means take advantage of the existing natural forces which aid in increasing the ultimate recovery of oil. It has been demonstrated that water-flooding, whether natural or artificial, will increase the recovery of oil if properly controlled.

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* W. W. Scott presided at Tulsa; John F. Dodge at Los Angeles.

† Petroleum Engineer, U. S. Bureau of Mines.

However, there is one characteristic common to all of the production curves shown, with the possible exception of Fig. 7, which tends to discredit part of the benefit attributed to natural water-flooding. That is the deficiency in the production of the wells, when compared with the type decline curve, prior to the increased production caused by edge-water encroachment. In view of this, part of the production increase accompanied by encroaching edge water might be considered as deferred production due to some other cause.

In the Bradford district of northwestern Pennsylvania and southwestern New York State, where intensive water-flooding has been practiced for some time, I believe it is estimated that the percentage recovery of oil by ordinary methods of production is about 20 per cent. and that approximately 40 per cent. of the remaining oil is recovered by water-flooding—a total recovery of about 52 per cent. I believe that an equal total recovery of oil may be obtained by pressure maintenance, repressuring or gas-drive. After production has reached economic limits by these methods of increasing the recovery of oil, one can still exploit the pool by other methods. After flooding, the property is practically worthless in the light of present production practice and it is not probable that operators would attempt to recover the oil remaining in the sand.

A. F. Melcher,* Tulsa, Okla.—I think we can show by sand analysis just where plugs of edge waters come in. Take, for example, a sand that has a shale layer in the center, dividing the sand into two parts. Let the bottom be more permeable than the upper part, assuming the lower part to have three or four times the permeability of the upper part. In a well producing naturally the oil will first flow out of this lower zone of sand. The edge water, under pressure, will then penetrate this part of the sand and flow into the well, flooding out the oil in the top part of the sand, which may contain as much oil as the lower zone of sand at the beginning. If an analysis were made of this sand at the beginning, the permeability of the two layers of sand could be determined and the flow of oil from the lower zone of oil sand could be pinched down by putting a packer in the middle of the sand at the shale layer, so as to equalize the progress of the natural water-flood from top to bottom of the sand.

P. C. McConnell,† Taft, Calif.—During the last year or more we have been doing a considerable amount of work in attempting to control the edge water that naturally would appear after a prolonged development program such as this area has experienced. At present, by the use of proper back-pressures, we feel that in a few cases at least we have had very favorable results. We have found the first marked appearance of edge water to be moving up structure at the rate of probably 500 to 1000 ft. a year in certain areas. By the application of back-pressure, we have, so far as we can measure it, markedly retarded this movement. Of course, we have not stopped the movement of edge water. We are aware that so long as we take out the oil and the gas, water is going to move up structure, but we feel that we have retarded the front line of advance of the edge water.

This will have, we hope, a marked effect on the recovery of oil. At the present time it is difficult to estimate how much we will obtain in dollars and cents, but we believe that we are increasing the ultimate recovery markedly. We have not the worry regarding edge water in this area that commonly faced us in the past. We consider that edge water properly controlled is an aid rather than a detriment to maximum oil recovery. If we can hold it back and allow it to advance over a more or less uniform front, we feel we should increase our oil recovery by preventing the irregular advance of water that would otherwise tend to trap large bodies of oil and prevent recovery at some future date.

* Consulting Petroleum Engineer.

† Standard Oil Co.

C. M. Nickerson,* Los Angeles, Calif. (written discussion).—Mr. Wright's paper shows several types of decline curves for individual wells in the Mid-Continent area, where edge water has affected the oil production. In the Elk Hills oil field, California, several of the leases located on or near the productive limits of this large structure have decline curves very similiar to those illustrated. In this field the volume of water produced with the oil steadily increases each month, accompanied by a decline in the oil production. Prior to the time when the water cut increases to about 5 per cent., the individual well may show an increase in production each month for several months in succession. When the peak is reached the decline curve drops off rather sharply, while the water increases in volume to a marked extent, thus indicating a water-flooding factor. When this occurs the wells are repaired by plugging the bottom of the hole with a 10 or 20-ft. cement plug. Upon returning the well to production, practically all of the water difficulties are eliminated, while an increase in the volume of oil produced is obtained. The well is continued on production until the water content again rises to a point that adversely affects the oil recovery, when the plug is continued a few feet higher.

In those areas in the Elk Hills field where exceptionally large wells have been produced for several years, the edge-water line appears to advance much more rapidly towards such wells, which has been discussed by Mr. Wright. In other portions of the field where the rate of production has been steady, with no unusual flush areas, the edge-water line closely parallels the structure contours. The water is found ordinarily in the lower portions of the oil zone, and is excluded by bottom plugging. The rate of encroachment of the edge water is more rapid there than in the upper portions of the same zone, although the fluid maintains a higher back-pressure on the lower strata of the oil formation.

H. H. Wright.—Mr. Chalmers says that there is a characteristic common to the curves shown in the paper which tends to discredit part of the benefit attributed to natural water-flooding. This characteristic is a deficiency in production as compared with the type decline curve before the increased production caused by edge-water encroachment is evident. He holds that the production increase may be considered, in part at least, as deferred production due to some other cause.

It is unfortunate that it is necessary to pick out wells that show a delayed effect of edge-water encroachment to serve as examples. The Wilcox type curve in the Seminole area is influenced to some extent by edge-water encroachment. The evidence in the form of production graphs would be difficult to produce unless one were content to use those wells showing the effect somewhat delayed. However, the matter may be viewed in another light. If it is assumed that the average Wilcox sand thickness is 50 ft., that its porosity is 20 per cent., and that its saturation originally was 70 per cent., the recovery made from this producing sand would have to be somewhere between 40 and 50 per cent. efficient to date. This figure is rather high, and in view of the fact that there is possibly 10 per cent. yet to be recovered it appears that the high efficiency can be directly attributed to natural water-flood.

The effect of natural water-flood is not uniform in all parts of a pool. In those parts where water has followed up the dip at a rate in direct relation to the rate of gas and oil depletion, a well's production curve would be called typical of the sand. In other parts, where water has not encroached as rapidly and where oil has been recovered at the expense of a large reduction in formation pressure, the delayed action would be evidenced as shown by the curves in my paper. Furthermore, it is necessary to select edge wells which are actually producing water in order to show the effect of edge-water encroachment. Such wells, typically, are smaller than wells high on the structure and are likely to be less influenced by the effect of gas expansion.

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* Petroleum Engineer, U. S. Navy Department.

Increasing the Ultimate Recovery of Oil

By S. F. Shaw,* Tulsa, Okla.

(Tulsa Meeting, October, 1930)

The theory that maintaining a high back-pressure on the oil sand lowers the viscosity of the oil has been generally accepted. The theory has also been advanced that lower viscosity permits the oil to be moved through the sand to the well at an expenditure of less gas per barrel of oil than would otherwise be required. It seems reasonable to assume that production of oil at the minimum gas-oil ratio will result in a greater ultimate recovery of oil.

During the past five years the writer has acquired data on thousands of tests made on wells to determine the best rate at which to produce them. In the majority of cases reduction in back-pressure did not definitely increase the gas-oil ratio. The information obtained from these tests has raised doubt in the mind of the writer as to the correctness of the theory that lowered viscosity results in lower gas-oil ratios and in higher ultimate recovery of oil. The reasons that explain the results obtained in these tests cannot yet be definitely stated, but the hypothesis is being tentatively assumed that there are other factors which outweigh the influence of viscosity.

Energy in Gas Moves Oil to Well

The general opinion is that in most cases it is the energy in the gas that moves the oil to the well. In wells flowing naturally it is also the energy in the gas that lifts the oil to the surface. In a flowing well, there are two very distinct operations:

1. Moving the oil through the sand to the well.
2. Lifting the oil to the surface.

The more important function of the gas is that of moving the oil to the well. Means for lifting the oil can always be found once it has been delivered to the well.

Principles Involved in Lifting Oil

A well that flows naturally is the same as a gas-lift well except that all of the gas is supplied by the oil reservoir. This natural flow is subject

* Consulting Engineer, Carter Oil Co.

to the same physical laws and principles that govern artificial air-lift or gas-lift flow. In all gas-lift operations there are four significant capacities for any pipe through which the mixture of oil and gas is flowed These capacities are:[1]

1. Point of no flow caused by deficiency of gas.
2. Point of maximum efficiency.
3. Point of maximum capacity.
4. Point of no flow caused by excess of gas.

Fig. 1 illustrates these conditions. There will be no flow of liquid in the pipe until the quantity of gas at point A is exceeded, after which the flow starts and increases regularly until point C is reached. The flow then begins to diminish and is finally reduced to zero at point D. Point

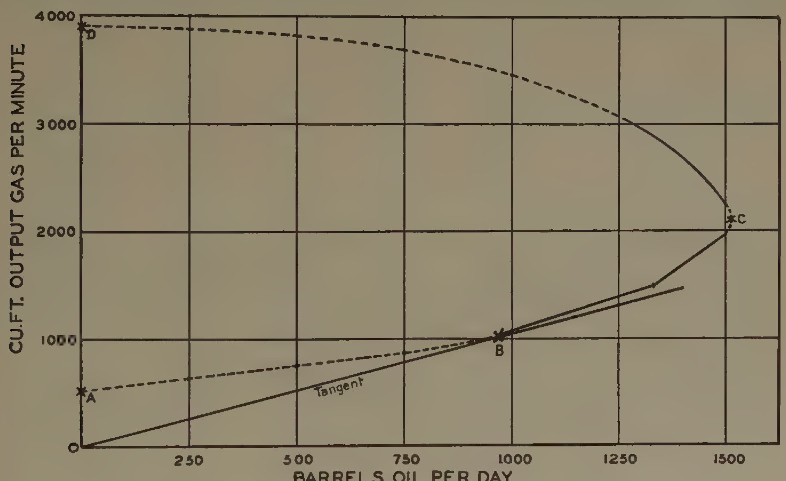

Fig. 1.—Relation between output gas and oil lifted.

B, the rate of highest lifting efficiency, is located on the curve where a straight line drawn from the origin of coordinates is tangent to the curve. The point of maximum lifting efficiency is reached before the point of maximum capacity is reached.

It has been stated that a velocity of 14 ft. per second is required to sustain in an air current a drop of water 1 mm. dia.[2]. If this is an exact determination, there will be required a velocity greater than 14 ft. per second actually to lift the liquid. The required minimum velocity to lift a liquid will depend on the character of the liquid, on the diameter of the drops of liquid and on the density of the gas.

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[1] S. F. Shaw: Some Observations on Principles Involved in Flowing Oil Wells. *Trans.* A. I. M. E., Petroleum Development and Technology (1930) 220.

[2] P. Lenard: Ueber Regen. *Meteorologische Ztsch.* (1904) **21**, 249–262.

Effect of Differential Pressure on Rate of Flow into Well

In large wells just completed, usually the production of oil and gas is greatest when the well starts flowing, or as soon as the loose sand and mud are cleaned out and the channels in the sand fully opened. The pressure in the well is at its maximum at this time, it is true, which might be interpreted to mean that lowered viscosity explains the maximum flow at this time. In making tests, however, the writer has found in many cases that reducing the pressure at the bottom of the well to a low point does not increase the gas-oil ratio. After the pressure is lowered below a certain critical differential, there will cease to be an increase in production of oil; yet the gas does not materially increase in volume, consequently it does not appear that increased viscosity, resulting from this lowered pressure, has had any appreciable effect on the flow into the well. The

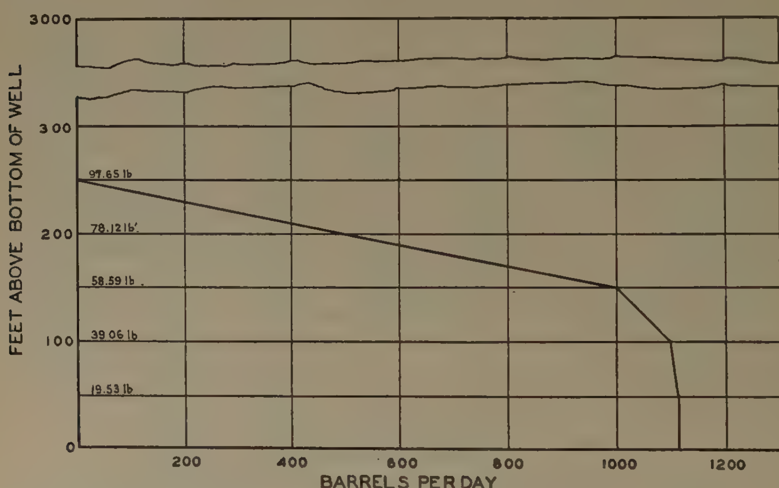

Fig. 2.—Relation between bottom-hole pressure and capacity.

reason that no increase of oil is made after this critical differential is reached probably is that the maximum filtering effect has been reached with the given set of conditions of rock pressure, porosity, velocity, viscosity, shape of sand grain, surface exposed to the borehole and perhaps several other factors at this time unknown to us.

In a paper presented before the A. P. I.[3] data were given on back-pressures as affecting the flow of oil into the well. The explanation was advanced that the oil and gas are caused to flow into the well by a differential pressure set up between the oil reservoir and the well, and that

[3] S. F. Shaw: Well Back Pressure and Fluid Levels. *Oil & Gas Jnl.* (Nov. 22, 1928) **27,** 50.

the flow of oil and gas would increase as the pressure at the bottom of the well is lowered until the critical differential pressure is reached, after which there would be no further increase in the flow even though there were further increase in the differential pressure. The rate of increase in the flow of oil does not continue in proportion with the reduction of pressure at the bottom of the well. Data in Table 1 will serve as an illustration. These relations are illustrated in Fig. 2.

TABLE 1.—*Production Obtained by Changes in Back-pressure at Bottom of Well*

Pressure at Bottom, Lb.	Fluid Level, Ft.	Oil Production, Bbl. per Day
97.65	250	0
78.12	200	500
58.59	150	1000
39.06	100	1100
19.53	50	1110
0.0	0	1110

With the possible exception of wells having a large excess of gas, the total increase of gas that accompanies an increase in production of oil when lifted at the best rate seems to be proportional to the increase in oil; that is, there appears to be no appreciable change in the gas-oil ratio. In areas where there is insufficient gas to lift all of the oil that would flow into the well, the writer has found that, in most cases, a change from natural flow to artificial flow by means of gas-lift would maintain as low a gas-oil ratio as previously, or would even result in a reduction in the gas-oil ratio.

The gas, from which the gas-oil ratio is computed, consists of methane, ethane, propane and the heavier gasoline vapors. Because of the greater stripping effect of the heavier gasoline vapors caused by using dry gas in gas-lift operations, gas-oil ratios obtained in gas-lift operations may appear to be higher than those obtained by natural flow or on the pump. This may be only an apparent increase, however.

Tests have been made which show that, in lifting oil with dry gas in the Seminole field, the gravity of the oil is reduced from about 41° Bé. to a gravity as low as 37° Bé. The gravity of the oil will be lowered to a greater extent in small wells on gas-lift than in larger wells, because the gas-lift factor is higher in small wells than in large wells, which results in an increased stripping effect. Table 2 covers a range of production from 93 bbl. per day to 4176 bbl. per day. These tests were conducted so as to obtain the maximum production, and after the maximum production was reached an additional quantity of dry input gas was admitted until a definite reduction in production was obtained.

TABLE 2.—*Gas-oil Ratios Obtained for Different Rates of Production*

Well Number and Lease	Maximum Production, Bbl. per Day	Gas per Bbl., Cu. Ft.		Production with Gas-lift, Bbl. per Day	Gas per Bbl., Cu. Ft.	
		Total Output	Natural Gas-oil Ratio		Total Output	Gas-oil Ratio with Gas-lift
3 Jones	93	12,360	990	79	19,630	1280
1 S. Walker	96	14,150	2550	82	18,000	2970
1 Jackson	103	10,150	2010	94	11,500	2300
10 Wise	103	12,010	3830	78	17,850	4200
1 S. Walker	110	13,120	2030	88	18,070	2820
1 Jones	158	9,900	1250	140	14,130	1630
2 Jones	162	9,620	1170	43	51,700	3200
8 Wise	170	9,575	3300	162	11,700	3500
9 Wise	210	9,220	2600	201	10,290	3030
1 Bowlegs	240	6,300	850	223	8,530	990
12 Killingsworth	292	5,760	1070	278	8,050	1330
4 J. Larney	337	4,880	1735	325	5,630	1955
3 Thomas	346	4,115	895	346	4,775	1075
1 Strother	385	5,600	1150	320	9,700	1610
4 J. Larney	443	3,410	1200	418	4,010	1310
2 J. Larney	500	3,920	1000	500	4,280	1170
2 Melisse	560	2,587	812	477	4,570	1115
3 J. Larney	562	3,150	710	562	3,340	835
1 Melisse	570	2,120	767	544	2,960	838
3 Fuswa	586	2,280	507	417	4,110	615
2 Melisse	594	3,162	852	570	3,942	976
2 Melisse	617	2,770	797	572	3,950	1050
5 Frazier	648	3,047	1435	598	3,742	1504
6 James	685	2,470	705	550	2,460	765
1 Strothers	722	2,880	1323	696	4,046	1427
1 Melisse	740	2,642	710	716	3,900	925
5 Frazier	765	2,947	1341	746	3,315	1413
1 McMann	840	2,620	740	770	3,500	830
6 James	864	2,300	595	756	3,153	694
1 Coker	886	1,830	450	833	2,143	527
1 Killingsworth	888	3,007	2122	744	5,000	2303
6 James	888	2,077	604	805	2,693	733
11 Killingsworth	895	2,836	1800	729	4,035	1975
1 Strother	896	2,391	987	230	2,961	1009
2 Coker	1025	1,402	482	780	2,770	530
10 Killingsworth	1080	2,790	1080	1034	3,528	1188
10 Killingsworth	1126	2,700	934	1101	3,206	1003
2 Coker	1224	1,477	334	1220	1,656	433
1 Gilliam	1417	1,272	434	1404	1,557	573
2 Coker	1423	1,511	408	1422	1,608	481
3 J. Walker	1530	1,650	520	1510	1,992	556
1 C. Harjo	2232	1,400	578	2203	1,680	718
1 Wrightsman	4176	1,218	792	3960	1,383	832

If an air jet were placed in a vessel of oil and the oil were agitated thoroughly for several hours by the jet, there would be considerable extraction of gas or gasoline vapors from the oil, and the degree of extraction of these vapors would vary according to the violence of the agitation and the length of time that the oil was agitated. Somewhat similar to this action is the stripping effect caused by using large quantities of dry gas in gas-lift operations (Table 3).

TABLE 3.—*Stripping Effect Caused by Increasing Quantity of Input Gas*

Oil Production Bbl. per Day	Total Gas per Minute, Cu. Ft.			Gas per Barrel Oil, Cu. Ft.		
	Input	Output	From Sand	Input	Output	Gas-oil Ratio
826	830	1,273	443	1,445	2,217	772
826	1,055	1,539	484	1,837	2,680	843
826	1,285	1,819	533	2,240	3,167	927

There was no increase in the oil production, therefore there should have been no appreciable change in the back-pressure at the bottom of the well; nevertheless, the gas-oil ratio apparently continued to increase with the increased quantity of input gas per barrel of oil.

Effect of Back-pressures on Gas-oil Ratios

The use of back-pressures has been shown to have the opposite effect to that of stripping the oil, in that considerable quantities of gas and gasoline vapors are left in the oil and therefore are not measured. The example in Table 4 illustrates the effect of using back-pressures on wells in the Santa Fe Springs field, California.[4]

TABLE 4.—*Effect of Back-pressures on Gas-oil Ratios*

Oil Production, Bbl. per 24 Hr.	Total Gas-oil Ratio, Cu. Ft. per Bbl.	Primary Trap Data			Secondary Trap Data		
		Temperature, Deg. F.	Pressure, Lb. per Sq. In.	Gas-Oil Ratio, Cu. Ft. per Bbl.	Temperature, Deg. F.	Pressure, Lb. per Sq. In.	Dissolved and Entrained Gas in Oil, Cu. Ft. per. Bbl.
5155	2819	128	300	2576	96	16	243
4067	1256	132	300	869	109	16	387
4175	1518	131	300	1241	112	8	277
5826	4430	123	300	4090	104	14	340
2622	3775	125	200	3640	95	7	135
3326	3165	122	200	2980	92	9	175

Table 4 indicates that when oil and gas are separated under back-pressure considerable quantities of gas accompany the oil to the secondary separator, and the higher back-pressures allow the greater quantities of gas to be carried along with the oil. In the second case cited in the table, the gas that was carried out with the oil to the secondary separator amounted to an increase of 44 per cent. of that measured in the first separator. Also, the percentage of discrepancy appears to become greater as the gas-oil ratios decrease. Where back-pressures are employed

[4] C. V. Taylor: Modern Gas Trap Installation. Paper read before the California Natural Gas Assn., February, 1929.

inspection of the tank batteries usually reveals a considerable quantity of gas escaping with the oil.

Action in Wells Having a Large Excess of Gas

In wells where there is a large excess of gas over that required to lift the maximum quantity of oil, gas-oil ratios have been regulated or reduced in some cases by the use of beans. It has appeared to the writer, however, that such instances usually accompany the use of tubing that is not the best size for the best rate of production. An instance may be cited in a well 3256 ft. deep with 6⅝-in. casing and 3246 ft. of 3-in. tubing, from which the data of Table 5 were obtained.

Table 5.—*Effect on Gas-oil Ratios Caused by Increasing Production*

Flow Tubing Size, In.	Pressure, Lb.		Oil, Bbl. per Day	Gas	
	Casing	Trap		Per Minute, Cu. Ft.	Gas-oil Ratio
3	265	132	227	1,890	11,980
3	246	99	235	1,980	12,130
3	223	46	242	2,078	12,350
Between 6⅝ and 3	[a]	200	174	1,600	13,250
	[a]	144	211	1,829	12,470
	[a]	93	228	2,040	12,870
	[a]	50	443	2,272	7,375

[a] No pressures were obtained on the tubing when flowing between the tubing and casing.

It will be noted that the flow through the annular space between the 6⅝-in. and the 3-in. tubings resulted in higher gas-oil ratios for a production of 174 bbl. per day with trap pressure of 200 lb. than the flow through the 3-in. tubing. However, when the trap pressure was lowered to 50 lb., the production increased to 443 bbl. per day and the gas-oil ratio was reduced to a figure much below the best rate possible to obtain when flowing through the 3-in. tubing.

Instances similar to the example noted in Table 5 may be given of wells flowing naturally that were afterward changed to gas-lift operation. The results in regard to gas-oil ratios are given in Table 6.

Table 6.—*Gas-oil Ratios in Wells Flowing Naturally and on Gas-lift*

Well	Method of Flowing	Depth of Tubing or Casing, Ft.	Oil, Bbl. per Day	Gas per Minute, Cu. Ft.			Gas per Barrel, Cu. Ft.		
				Input	Output	Sand	Input	Output	Gas-oil Ratio
A	Natural	4340	975		911	911		1345	1345
A	Gas-lift	4340	1295	341	1284	943	378	1429	1051
B	Natural	4347	511		420	420		1440	1440
B	Gas-lift	4347	1479	978	1882	904	952	1832	880

Instances may be cited, as in Table 7, which indicate that gas-oil ratios were not materially affected by reducing the back-pressure in wells flowing naturally.

TABLE 7.—*Effect on Gas-oil Ratios of Lowering Back-pressures*

Well	Length Tubing, Ft.	Diameter of Bean, In.	Pressure at Well, Lb.	Pressure at Bean, Lb.	Oil, Bbl. per Day	Gas-oil Ratio, Cu. Ft. per Bbl.
C	1708	3/8			161	1448
C	1708	1			457	1345
C	1708	3			522	1296
B		4-in. pipe	35	0	1475	492
B		1/2	210	180	689	418
B		5/8	205	175	1353	431
B		3/4	200	160	1471	479
B		7/8	180	128	1612	490
D		1	175	105	1709	487
D		3/8	200	180	573	475
E		1/8	190	185	103 1/2	427
E		1/4	205	200	318	440
E		3/8	225	215	328	485
E		1/2	225	185	728	485

The increases or reductions in the gas-oil ratios shown in Table 7 are too small to admit the conclusion that there was any actual change in gas-oil ratios when we consider the possibilities of error in reading orifice meters and the tendencies for gas to escape without being measured.

When due precautions are observed as to the use of the best size of tubing, and corrections are made to obtain the actual gas-oil ratios under equivalent standard conditions, it may be found that, even in wells with large excess of gas, the use of back-pressures at the casinghead may not secure the lowest gas-oil ratios. If, then, it should be found that lower gas-oil ratios are not obtained by holding back-pressures either in gas-lift wells or in wells flowing naturally, the theory as to the use of higher back-pressures to obtain lower viscosity fails, so far as being a critical factor in ultimate recovery.

Velocities of Flow through Oil Sands

It will be interesting to examine the effect of underground velocities. We may take the case of a well with sand thickness of 25 ft. pore openings at the well at 8 per cent. diameter at the bottom of the well of 6 in.; flow into the well of 1000 cu. ft. of gas per minute, or 1,440,000 cu. ft. per day under bottom-hole pressure of 130 lb., with 1000 bbl. of oil per day. Under these conditions the velocity at the entrance to the well would be 0.55 ft. per second. At 10 ft. from the well the velocity would be 0.014 ft. per second, and at 100 ft. distance the velocity would be 0.0014

ft. per second. With bottom-hole pressure at the well of 130 lb., the rock pressure at 100 ft. distance from the well would be considerably greater than 130 lb. and the velocity would be correspondingly reduced. If the production were 5000 bbl. per day, accompanied by 5,000,000 cu. ft. of gas, and the bottom-hole pressure were 300 lb., the velocity at entrance to the wells with the same assumed sand thickness would be 0.95 ft. per second. The pore openings at the periphery of most wells probably is several times that assumed above, therefore velocities are usually much lower than in the cases assumed.

With the low velocities noted, there may be a tendency for the gas to escape from the oil without moving the oil through the sand. At any rate it may be that such velocities are so low as to be very inefficient and any increase in velocity that is practicable to obtain up to the maximum flow conditions may tend toward a large increase in the efficiency of the flow. This condition of increased velocity can be brought about by lowering the pressure at the well to the point of the critical differential pressure.

Attention has been called previously to the fact that if the velocity is too low, perhaps under 14 ft. per second, no liquid will be lifted in gas-lift work through long pipes, because the gas will separate from the oil and will escape without serving any useful purpose. If we attempt to flow a mixture of oil and gas through a horizontal flow line, we find that the efficiency is very low. If a number of obstructions or bends are placed in this horizontal flow line, the efficiency is still further reduced. This condition of inefficiency will finally reach a point at which the flow will cease entirely and the gas will stratify and flow above the oil, unless greater pressure condition is set up to overcome these obstructions.

It is true that the flow through the sand is not exactly analogous to the lifting of oil in a vertical pipe, but in somewhat similar manner to the flow through a horizontal pipe, the flow through an oil sand must be at low efficiency when computed on a foot-pound energy basis.

After the oil close to the well has been removed, the oil at a greater distance must be propelled to the well through a distance that becomes increasingly greater and this must be done at an increasing expenditure of energy. The velocity of flow increases as the moving mixture of oil and gas approaches the well; conversely, the velocity gradually becomes reduced as the distance from the well increases. The problem of moving oil into the well is affected not so much by excessive velocities close to the well as by a velocity at a distance from the well that is too low to move the oil through the winding channels of the sand. The movement is so slow that the gas tends to escape from the oil without moving the oil toward the well. The low velocity at a distance from the well, coupled with the increasing distance that the oil must be moved through the sand, gradually reduces the quantity of oil that eventually will reach the well.

Another basis on which the propulsion of oil through the sand might be considered is that of the energy released by the gas during the flow to the well. A perfect gas in expanding isothermally to atmospheric pressure (14.7 lb. per sq. in. absolute at sea level) develops a definite number of foot-pounds of work, as noted in Table 8.

TABLE 8.—*Foot-pounds of Work Developed When a Perfect Gas Expands Isothermally to Atmospheric Pressure of* 14.7 *Lb. Absolute*

Gage Pressure, Lb. per Sq. In.	Foot-pounds Work Developed	Gage Pressure, Lb. per Sq. In.	Foot-pounds Work Developed
1000	8964	500	7527
900	8744	400	7069
800	8499	300	6486
700	8222	200	5676
600	7902	100	4349

In flowing through the sand, the gas expands from the rock pressure to the pressure existing at the bottom of the well, and the maximum amount of energy available for propulsion of oil is the difference in foot-pounds existing at these respective pressures. Thus, if the rock pressure is 1000 lb., and a back-pressure is held such that the pressure at the bottom of the well is 600 lb., the maximum energy that can be developed is the difference between 8964 and 7902 ft-lb., or 1062 ft-lb. If the pressure at the bottom of the well is reduced to 200 lb. the energy available for propulsion of the oil is 3288 ft-lb. The reduction of pressure at the bottom of the well from 600 to 200 lb. would, therefore, increase to three times the energy available for moving oil through the sand.

Some of the gases associated with the oil are liquids when the pressure is high and are not available as a source of energy until the pressure is reduced enough so that they can assume the gaseous state. When in a liquid state these gases require the use of other fixed gases to propel them through the sand.

Reduction of back-pressure at the top of the well has the effect of reducing the back-pressure at the bottom of the well to some practicable limit and increases the energy available in the gas for moving the oil through the sand. Moreover, removal of the back-pressure at the top of the well increases the energy in the gas available for lifting the oil from the bottom to the top of the well. The question that remains to be answered is whether this energy can be applied more efficiently in one case than in the other. The deductions from thousands of tests supervised by the writer is that the energy is more efficiently applied when employing low back-pressures than when employing high back-pressures

Once a given well spacing has been adopted, the distance that the oil must be moved and the number of obstructions in the path of the oil

cannot be changed, but the velocity can be controlled to some extent by reducing the flowing pressure at the well to the critical point, especially if this is done while the pressure in the sand is still high.

We are puzzled, at times, to understand why a producing well that has been closed for a time shows a loss of production when reopened. It seems possible that a readjustment of pressures takes place between the saturated oil sand and the area immediately surrounding the well after the well has been shut in. In this readjustment the gas escapes so slowly from the saturated portion of the sand that the velocity is not sufficient to move the oil toward the well. This movement of gas will continue, however, until pressure equilibrium is established, even though there may be no movement of the oil.

The theory has been advanced[5] that enlarging a well where it penetrates the oil sand will be productive of good results. The writer is of the opinion that the enlargement of the diameter of the well at the bottom would be far more beneficial in increasing the ultimate recovery than the use of back-pressures. Shooting wells has the effect of enlarging the hole, and has given satisfactory results in the Mid-Continent field. Observations made on several wells in the Seminole area indicated that the gas-oil ratio was lowered when production was increased by shooting the wells. Examples of reducing gas-oil ratios by shooting are given in Table 9.

TABLE 9.—*Effect on Gas-oil Ratios Produced by Shooting Wells*

Well	Oil Production, Bbl. per Day		Gas-oil Ratios	
	Before Shooting	After Shooting	Before Shooting	After Shooting
A	335	677	1320	853
B	454	671	850	675
C	368	606	1290	881
D	382	854	1923	1518
E	687	602	1264	1530
F	788	1475	600	444
G	395	724	973	698
H	732	1969	548	654
I	171	279	970	900
J	181	228	2250	2450
K	206	497	2580	1591

In nearly every case there was a reduction in the gas-oil ratio after shooting the wells. In the cases where there was no reduction in the gas-oil ratio, the tests were made at intervals too far apart, before and after the shooting, to give a fair comparison.

[5] L. C. Uren: Increasing Production of Petroleum by Increasing Diameter of Wells. *Trans.* A. I. M. E. (1925) **71,** 1276.

Conclusions

1. The laws governing the filtering effect of mixtures of oil and gas in passing through a porous sand medium probably have far greater effect on production of oil, under the various conditions that exist in the sand, than the single factor of viscosity as influenced by back-pressures. In other words, viscosity is only one factor under existing underground conditions, and probably is a relatively unimportant factor.

2. The explanation suggested by the writer is that while a high back-pressure may reduce the viscosity of the oil, it tends to reduce the velocity of flow through the sand to a point where the moving gas will not carry with it the maximum load of oil. In other words, the available energy in the gas is not utilized to maximum advantage.

3. The method of production tentatively suggested for obtaining the maximum ultimate recovery of oil is to enlarge the filtering area through the oil sand at the bottom of the well as much as practicable and to reduce back-pressures at the sand to the critical differential pressure.

DISCUSSION

(*W. W. Scott presiding*)

C. E. Beecher,* Bartlesville, Okla.—The title of Mr. Shaw's paper is Increasing the Ultimate Recovery of Oil, but the methods suggested are not essentially different from what might be termed common practice. The majority of engineers recognize these methods as not being suitable for increasing the ultimate recovery of oil. In fact, it is the changes in these methods that are needed to recover a greater percentage of the oil. In the conclusions, Mr. Shaw points out the advantages of the "filtering effects" of oil and gas, or what might be termed the "sweeping effect" of gas in moving oil through the sand, as being a more important factor in producing oil than the reduction of viscosity resulting from back-pressure, and refers to the viscosity factor as being a relatively unimportant one. He suggests enlarging the well diameter and reducing the back-pressure to produce a certain critical differential pressure at the sand as a means of obtaining maximum ultimate recovery.

The flow of oil through the small openings of the average sand must be of a viscous nature and the pressure required to produce a given flow varies directly as the viscosity of the oil, if other conditions are constant. Of course, bubbles of gas must move with the oil, and these add an unknown factor to the flow formulas, but the fact remains that the energy required to produce flow will be less if the bubbles are small and the viscosity of the oil low. To maintain these conditions back-pressures must be held on the face of the sand. Mr. Shaw suggests that low velocities may be very inefficient and recommends increasing the velocities by maintaining the critical differential pressure at the sand. Such conditions no doubt would result in greater immediate oil production but could hardly be expected to increase the ultimate production.

In general, high velocities will dissipate the energy available for moving oil through the sand, will result in the gas by-passing the oil, will strip the oil of its lighter hydrocarbons and increase both the viscosity and surface tension of the oil. All of these factors are not conducive to increasing ultimate recovery.

Apparently Mr. Shaw has gathered a lot of interesting and important data from individual well observations which no doubt are of great assistance in determining

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the proper method for producing these and other wells, but the conclusions based on these data do not, in my opinion, give evidence of increasing the ultimate recovery of oil.

An appreciable increase in the volume of oil recovered from the sand cannot be expected unless a more efficient use is made of the energy stored in the free gas and in the gas dissolved in the oil. To take advantage of this energy it seems necessary to operate an entire pool as a unit under conditions of high pressure and return energy to the sand in the form of gas, air or water under pressure.

H. D. Wilde, Jr.,* Houston, Tex.—Mr. Shaw presented an excellent discussion on the gas-lift and its operation—information that can be used to evaluate and better the efficiency of gas-lifts. There are, however, a number of points in the paper with which I take issue.

Mr. Shaw attempts to discredit the use of back-pressure in producing oil wells and advocates that the pressures on producing wells should always be kept low, thereby maintaining at all times a high pressure differential between the main body of the reservoir and the bottom of the wells. This, of course, means that the wells should be produced at or near their maximum rate. As the use of a gas-lift will decrease the bottom-hole pressure and increase the production rate, he advocates the use of additional gas to assist the natural formation gas in lifting the oil.

The argument is based on data he has accumulated showing that gas-oil ratios decrease as the production rates increase. He agrees with the generally accepted belief that in fields where water-drive is absent or unimportant, the energy in the reservoir gas drives the oil to the well, and that the lower the gas-oil ratio the greater the ultimate recovery of oil. Apparently then it follows that to get the greatest ultimate recovery, wells should be flowed wide open with little or no back-pressure on the producing sand.

My criticism is that he advocates this as a general rule to be followed in all fields under all conditions, and although no one will deny that his data are correct, and that in the field he has studied, which I believe is Seminole, under the existing production conditions greater rates of production were accompanied by lowered gas-oil ratios, it does not follow that this same thing is true in all fields. In fact, there are many fields where the data show the reverse to be true; that is, lower production rates give the lower ratios. Sugarland is one. There the chokes have been changed from time to time and the data show that in the overwhelming majority of wells, low production rates and low gas-oil ratios go together. Yates is another example. Those who are familiar with Yates may question this statement because there are many wells there where the reverse is true, but such wells are not tubed but are flowing in the casing. What I have said will apply to most of the tubed wells. Data have been taken recently on two wells at Yates and four at Sugarland to compare the effect of production on gas-oil ratio when flowing through casing set immediately above the pay and through tubing suspended practically to the bottom. Both types of flow were observed in the same well. I hesitate to dwell on this too much for fear of being guilty of generalizing too much on meager data, but it is true that in all six cases studied the relation was such that when the well was flowing through the casing gas-oil ratios decreased as the rate of production increased. When the well was flowing through the tubing, the ratio increased with the rate of production, then became practically constant and began to decrease slightly with increased production. We are hoping that further data will show that this is a general relationship for all cases where gas-oil ratios are affected by the production rate. It seems quite possible that in Seminole the data were taken on wells operating on the high-rate end of the curves.

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The tubed wells at Yates and Sugarland are undoubtedly operating on the low-rate end of the curve. In these wells, tubing and low production rates have lowered the ratios considerably below anything possible with high rates.

It seems then that what Mr. Shaw should have said is this: "If tests on the wells show that there is no other way to lower gas-oil ratios except by the elimination of back-pressure, the field should be produced wide open. Otherwise, the wells should be produced, in so far as it is compatible with market or proration demands, at such rates that the gas-oil ratios are at a minimum." The same procedure cannot be followed nor general rules adopted for all fields.

One serious objection to the method advocated by Mr. Shaw is that it is incompatible with the return of gas in the early stages for pressure maintenance. As the object of his method is to remove back-pressure at the wells and to deplete the pressure in the drainage area of each well as rapidly as possible, it is not feasible to return the gas produced with the oil to the reservoir and hold up the pressure in it. Although gas-oil ratios cannot be reduced below that dissolved in the oil at the rock pressure by ordinary methods, by returning the gas to the reservoir, the equivalent or net gas-oil ratio can be cut way below the dissolved amount; in fact, it can be reduced to almost zero. Consequently, if low gas-oil ratios and high ultimate recoveries go together, as most of us believe, gas return is a far better way than the elimination of back-pressure for getting high recoveries.

Work carried on recently by Professors Uren and George on moving saturated oil through sand in laboratory flow tubes indicates that as the pressure on the saturated oil moving to the well decreases gas comes out of solution, forming bubbles, which as they get larger offer increased resistance to flow. By holding back-pressure at the well, less gas is evolved and the bubbles remain smaller, minimizing the resistance and requiring less energy to move it. This is another argument in favor of holding back-pressures at the wells.

The argument used in the paper against back-pressures is that since the reduction of back-pressure should cause gas to come out of solution and increase the viscosity, one would expect that more energy and a greater gas-oil ratio should be required to produce the oil. However, some wells have shown lower gas-oil ratios under conditions where viscosities are higher; therefore, viscosity is not the controlling factor affecting gas-oil ratios. As the influence of low viscosity is not as important as that of some other factors, there is no need for holding back-pressures and the wells should be produced at the maximum rate. This argument is weak, for while it is true that viscosity is not the controlling factor, it does not prove that the other factors that are controlling may not be affected in such a way that greater back-pressures mean lower ratios. Many tests show that back-pressures do promote low ratios.

In discussing velocities through the sand, Mr. Shaw quotes the fact that an upward velocity of 14 ft. per second is required to prevent a drop of water 1 mm. in diameter from falling. He then argues that unless velocities in the sand are of this order of magnitude, gas will separate from the oil in the sand and flow to the well without carrying oil with it. He quotes figures to show that for an assumed well the velocity at the well would be 0.95 ft. per second, 10 ft. away 0.024, and 100 ft. away 0.0024 ft. per second if the back-pressure is 300 lb., but if the back-pressure is only 15 lb., the velocities are 10, 0.25 and 0.025 ft. per second. As the latter are more nearly equal to 14 ft. per second, the pushing action of the gas should be more efficient. However, to compare flow through sand with flow in vertical pipes and to say that comparable velocities are required for efficient flow is absurd. Flow of oil and gas mixtures through capillary, branched openings is vastly different from flow through a large vertical pipe. That efficient flow of oil and gas in sand is possible at extremely low rates without gas separation is borne out at Sugarland. Calculations similar to those in the paper have been made on one well and show a velocity of only 0.0009

ft. per second and yet gas-oil ratio only 247 ft. per barrel compared to a dissolved value of 211. This is indicative of highly efficient flow even with extremely low linear velocities. All Sugarland wells will show velocities in the sand of a similar order of magnitude.

E. O. Bennett,* Ponca City, Okla.—All our production is due to a given amount of energy in the formation and if it is not conserved we are losing oil. If by lowering the back-pressure we exceed a rate of flow by which the gas is doing the most useful work, we have to measure that from the known pressure conditions in the bottom of the well and the gas dissipated at those pressures. Higher back-pressures probably will give greater ultimate yield on account of lower energy used in obtaining the production. Gas in the oil does not have a chance to expand and lock the sand, so the percentage of energy needed to drive the oil to the well will be at a minimum at high back-pressures.

Another reason why I like to look at the higher back-pressure is that it results in a minimum differential in pressure between the well bore and the formation. Under those conditions with more complete saturation, there is a lesser distance to go and it requires less energy to move the oil to the well. Another condition is that saturation near the well bore is more complete. The amount of by-passing at low back-pressures is several times as much as necessary to raise the oil through the tubing.

I agree with Mr. Wilde that Mr. Shaw's data may be true for this particular case, but are not generally applicable.

J. R. McWilliams,† Tulsa, Okla.—Mr. Shaw says that by decreasing the pressure at the bottom of a well, the oil production increases with no appreciable increase in the gas-oil ratio, and that this condition holds true until a critical bottom-hole pressure is reached, when a further reduction in bottom-hole pressure does not increase the oil production yet the gas volume does not materially increase. I agree with these conclusions and that the immediate maximum daily rate of oil production can be obtained by so flowing a well that its bottom-hole pressure is near the critical point. Under competitive operating conditions, an operator is probably justified if not forced to produce his wells at their maximum daily rate, but I believe the ultimate recovery of oil from all the wells in the pool is jeopardized under these conditions.

Water encroachment is aggravated by reducing the bottom-hole pressure of the wells to their critical points, or water encroachment is hastened by operating the wells at their maximum daily rate of oil production. If edge water is forced to travel slowly upslope or bottom-hole water is allowed to rise slowly over the area as a whole, instead of coming in the immediate vicinity of the wells, the result can only be that less oil is trapped in the sand and more oil will be recovered ultimately.

J. Chalmers,‡ Bartlesville, Okla.—I believe the time factor in the production of oil is a very important one and one which many of us are inclined to overlook. One of our laboratory experiments, while it may not apply directly to field operation, should give some indication as to the importance of the time factor in oil recovery. We depleted the two sand-packed flow tubes of about 8 per cent. of their oil content at complete saturation by natural flow. One tube we immediately repressured, the other we allowed to stand for two weeks before repressuring. To recover a given amount of oil the second tube required about three times the amount of gas that was required by the first tube, which was repressured immediately. I think that is a definite example of what gravitational separation of the oil and gas in the sand will

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do. This applies only where gas expansion is the direct cause of the movement of oil into the producing wells and the water-flood, natural or artificial, is not brought into play. The same would hold true in the field where water is absent.

S. F. Shaw (written discussion).—Mr. Beecher is correct, I believe, in stating that the majority of engineers do not recognize the methods proposed by the author as suitable for increasing the ultimate recovery. The present time is not propitious for carrying out more extended application of these methods, but I am hopeful of convincing this majority in the course of time that these methods are applicable for the purpose proposed, that the reasoning given is in accordance with proved physical laws, and that practical demonstration has already provided more proof than the majority is now willing to concede.

I am of the opinion that the experiments made on viscosity effects of oil containing gas under pressure were not made under conditions paralleling actual reservoir conditions, and that these reservoir conditions would tend to modify greatly the effects observed. I believe that experiments are now under way, or are proposed, by Professor Uren, which will explain some of these points more clearly.

The majority of my observations were made in the Seminole field, and the high recovery already obtained in the older portions of the field amounting to about 60 per cent. would seem to lend support to the arguments given. However, Seminole did not contribute all of the data, since these were obtained in person from something more than 1000 wells situated in Colombia, Peru, Rumania and various parts of the United States, including Tonkawa, Braman, Bristow, Garber, Independence (Kans.), Carter-Knox, Burbank, Luling, Mirando City, various Gulf Coast fields and several of the Los Angeles Basin fields.

Mr. Wilde refers to Sugarland as a field in which gas-oil ratios are held at a low point, but this does not indicate higher ultimate recovery. A low gas-oil ratio at this time does not necessarily imply that the gas-oil ratio will be low one year later. This field has produced only between 5 and 10 per cent. of the oil supposed to be contained in the reservoir, hence any conclusions as to ultimate recovery must be held in abeyance. If I mistake not, some of the tests that have been made at Sugarland along lines proposed in my paper as beneficial did not increase the gas-oil ratios. Back-pressures have been held at Raccoon Bend, where it was hoped that this would result in low gas-oil ratios and would prevent or delay water encroachment, but the desired results at this time do not seem to have been achieved.

I believe, however, that where it is desired to curtail production, the work at Sugarland has shown that this object can in certain cases be achieved through the use of high back-pressures with surprisingly low gas-oil ratios. This is accomplished by employing a small diameter of tubing for producing a small quantity of oil where bottom-hole pressures are high. Up to this time I do not know of any method that is superior to that in use at Sugarland for curtailing production.

Mr. Chalmers' discussion notes the results of an experiment in repressuring in which a delay required three times as much gas to recover a given amount of oil as where the repressuring was done immediately. It seems to me that this tends to add confirmation to my suggestion that delayed or slow velocity tends toward a separation and stratification of the gas and oil in the sand.

Bottom-hole Pressures in Oil Wells*

By C. V. Millikan,† Tulsa, Okla. and Carroll V. Sidwell,‡ Seminole, Okla.

(Tulsa Meeting, October, 1930)

There is nothing more important in petroleum engineering than a definite knowledge of the pressure at the bottom of an oil well at any existing operating condition, and the relation of this pressure to the pressure within the producing formation. A knowledge of bottom-hole pressures is fundamental in determining the most efficient methods of recovery and the most efficient lifting procedure, yet there is less information about these pressures than about any other part of the general problem of producing oil.

Determination of Bottom-hole Pressures

Bottom-hole pressure may be calculated or determined by several methods. On an inactive well it may be calculated from the fluid head or, if the well is shut in, by adding the casinghead pressure, the static head of the gas and the fluid head. In wells flowing naturally through tubing the pressure at the bottom of the tubing may be calculated by adding the pressure at the casinghead between the tubing and the casing and the pressure due to the weight of the column of gas, but there is always possibility of error caused by fluid being in the annular space above the bottom of the tubing. If a well with tubing is flowing through either the annular space or the tubing, sufficient gas may be injected through the static space to insure that it is free of fluid but not sufficient to establish an appreciable friction loss. The pressure at the bottom of the tubing can then be calculated by adding to the pressure at the tubing head the pressure due to the weight of the column of gas. This is probably the most accurate method of calculating bottom-hole pressures. In wells flowing by gas-lift, the pressure at the point the gas enters the flow may be calculated by a gas-flow formula.

Several types of pressure bombs have been used to measure the pressure at the bottom of wells. One is a piece of steel tubing with a check valve in the bottom and a connection for a pressure gage at the top. It is lowered into the well to the point at which the pressure is

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† Chief Production Engineer, Amerada Petroleum Corporation.

‡ Production Engineer, Amerada Petroleum Corporation.

desired, then brought to the surface and the pressure read from a pressure gage put on the top connection. Several bombs have been made which enclose a maximum reading pressure gage. Some use a maximum indicating pointer, but this is not as satisfactory as a stylus on the pointer scratching a smoked surface. Consideration has been given to electrical instruments that can be lowered into a well and made to give a continuous reading at the surface, but so far as is known, this method has not yet been developed to practical use. A recording gage built up with a common gage-pressure element, recording on a small circular clock-driven chart, has been used occasionally, but its use is limited because of its large diameter and difficulty of close reading. Another recording gage is being developed by which the pressure is determined with a piston and spring, on the same principle as an engine indicator gage, and another obtains the pressure from a fluid-filled tube with elastic walls.

The Amerada pressure gage was used in determining the bottom-hole pressures considered in this paper. It was developed in the laboratory of the Geophysical Research Corpn. under the direction of Dr. F. M. Kannenstine. A cross-sectional drawing of the instrument is shown in Fig. 1. The gage consists of three main parts: clock, chart-carrier, and pressure element. The clock is of special design, having a diameter of 1⅜ in. and an overall length of 7 in. The carrier holds a chart 7 in. long and 2⅞ in. wide. The movement of the chart is obtained by a central screw operated by the clock. This screw drives the chart carrier downward so that its weight almost balances the friction and thus reduces the power demand on the clock. The pressure element consists of pressure-element tubing, fabricated into a spiral coil ⅞ in. in diameter and 7 in. long. The lower end of this tube is soldered to an opening in the base, which extends to the outside of the bomb. The upper end is sealed and attached to a shaft, to which is also attached an arm and brass stylus for recording on a metallic-faced paper chart. The entire instrument is built on a frame which fits into a steel case, and as it is run into the well is 41 in. long, 2 in. outside diameter and weighs 25 lb. It is usually run on a steel-wire measuring line.

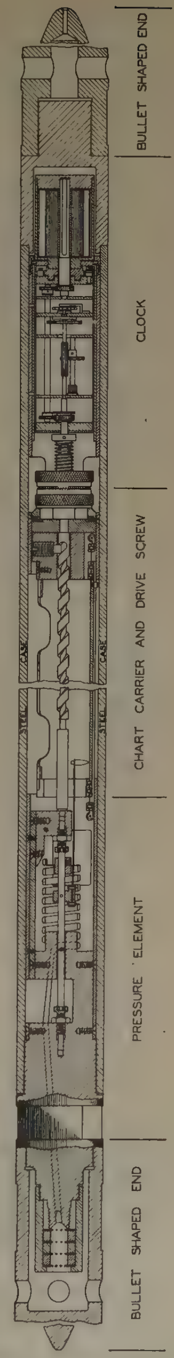

FIG. 1.—CROSS-SECTION OF AMERADA PRESSURE GAGE.

Clocks of five different speeds have been made, which will run the full length of a chart in one, three, twelve, twenty-four or forty-eight hours. Pressure elements of various ranges may be used. The lowest

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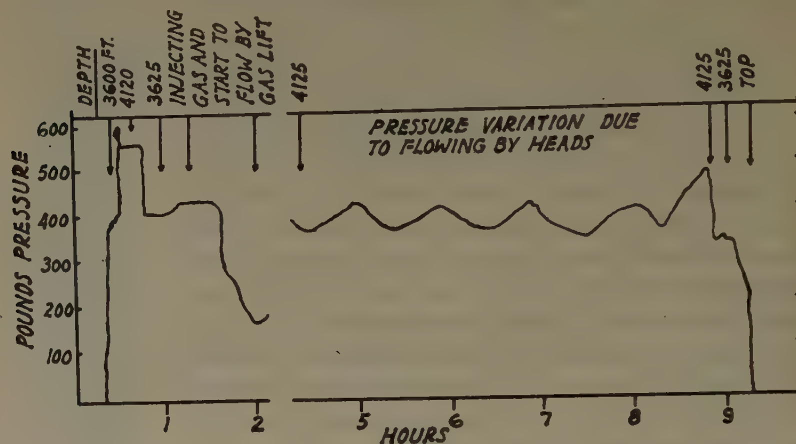

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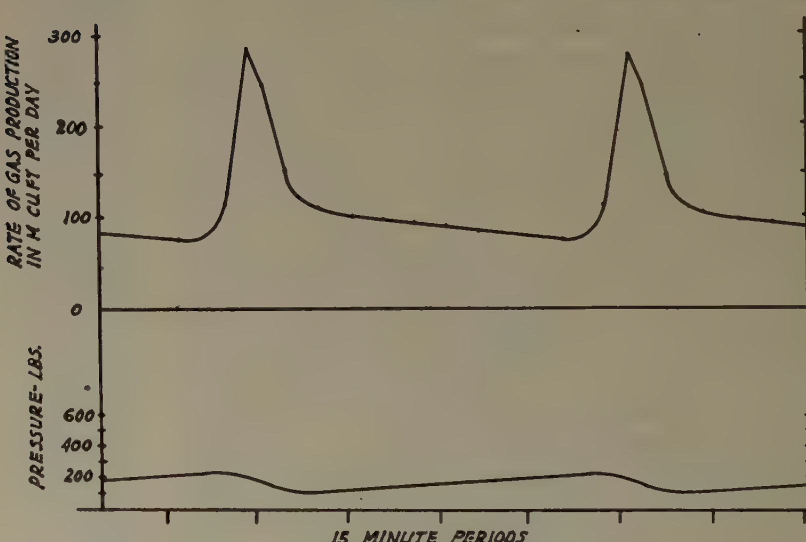


Fig. 2.—Chart from well producing on gas-lift.

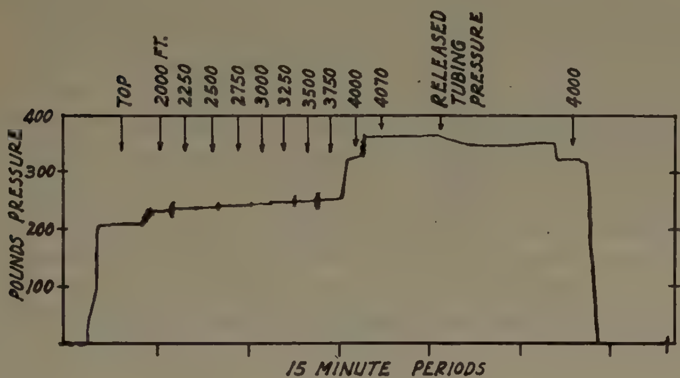
Instrument was at bottom of hole while gas was being injected. Pressure increased at time gas injection was started, and dropped when well began to flow. Note pressure variation caused by flowing by heads.

Fig. 3.—Pressure change in bottom of well flowing naturally by heads, and rate of gas production on same time scale.

range used thus far has a calibration of 75 lb., and the highest has a calibration of 1100 lb. per inch of movement of the stylus. In most cases, temperature correction may be neglected. The chart reading will be approximately 1 lb. low for each 65° F. increase in temperature.

Although this instrument appears to be delicate, service in the field has proved that it will stand hard usage.

Five charts taken in producing wells are reproduced in Figs. 2 to 6 inclusive. The pressure scale and notes showing depths of readings



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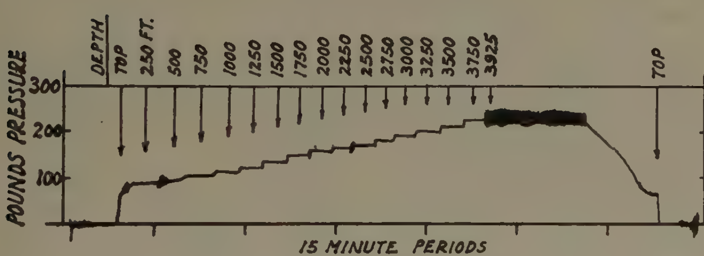

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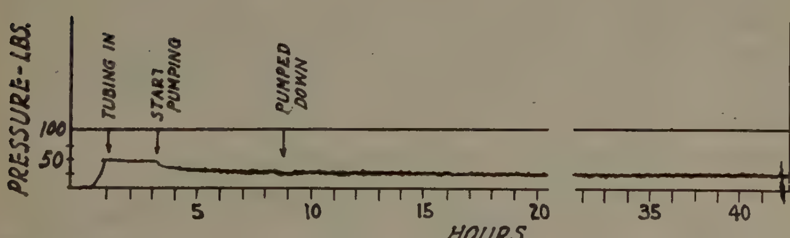

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Fig. 4.—Pressure increase down to 3830 ft. is due to weight of gas column. Below 3830 ft. increase due to fluid head.

Fig. 5.—Pressure chart from well flowing naturally. Instrument was suspended for a time at each of indicated depths.

Fig. 6.—Pressure below working barrel in pumping well.

and some of the changes in the well which caused a change in pressure have been added. The chart shown in Fig. 2 was made in a well producing by gas-lift, flowing between 2½-in. tubing and 7-in. casing. The bottom of the tubing was 3602 ft. and the top of the sand at 4124 ft.

Readings were taken near these depths before gas was injected to start the well flowing. The pressure of 558 lb. recorded at 4120 ft. was considered as the pressure in the producing formation. The pressure at the bottom of the tubing increased 26 lb. after starting to inject gas, probably owing to the weight of the gas under pressure. During the last five hours of the chart the well was flowing by heads at the rate of 1560 bbl. per day, with an input volume of 940,000 cu. ft. and a trap volume of 1,600,000 cu. ft. per day. The chart shown in Fig. 3 was taken in a well flowing by heads at the rate of 580 bbl. of oil per day, from 3935 ft. through 8⅝ in. casing. The formation pressure at the top of the pay zone was 1520 lb. The rate of gas production, which is plotted simultaneously with the pressure at the bottom of the hole, was obtained with an orifice meter, using a fast meter chart. The time, pressures and gas volume were repeated with marked regularity during each flow. The chart reproduced in Fig. 4 was taken in a well that had been flowing by gas-lift, but was shut down at the time the chart was taken and still had a tubing-head pressure of 224 lb. The increase in pressure due to the weight of the column of gas is recorded down to 3750 ft., where the pressure was 257 lb. From the pressure increase in fluid between 4000 and 4070 ft., and the pressure increase from the top to 3750 ft. in gas, the point at which the gage went into fluid is calculated at 3830 ft. When the tubing pressure was released the pressure at the bottom temporarily dropped only 15 lb., showing that the tubing filled with fluid almost as fast as the gas pressure in the tubing could be released. The chart shown in Fig. 5 was taken in a well producing at the rate of 2200 bbl. of oil and 2,500,000 cu. ft. of gas per day through 8⅝-in. casing. The chart shows pressures at intervals of 250 ft. in the flowing column of oil and gas. The excessive vibration of the gage while at 3925 ft. was probably caused by the gage hanging opposite a stratum of pay sand. The chart reproduced in Fig. 6 was taken in a pumping well and is explained in a later paragraph (p. 204). These charts are representative of a large number that have been obtained in wells producing under a wide variety of conditions.

Application of Bottom-hole Pressures

The value of determining pressures in different formations while drilling through them is shown in Table 1. These pressures were obtained in wells in the Carr City pool in the Seminole district, Seminole County, Oklahoma. Measured pressures in these formations permit certain precautions which might otherwise be overlooked. For example, in drilling it is the universal practice in the Seminole district to produce the small amount of oil which may occur in the Simpson with the "First Wilcox" sand. As these sands are usually drilled with cable tools, the much higher pressure in the Simpson would cause oil to flow from the hole into the "Wilcox" sand when the porous part of the

"Wilcox" is first encountered, and if the hole were not free from drill cuttings they might be packed so tight around the bit that a fishing job would result. It is not uncommon to find a large difference in the original pressures in formations that are separated by a relatively short vertical distance.

TABLE 1.—*Pressures Determined while Drilling in Carr City Pool*

Formation	Top, Ft.	Bottom, Ft.	Pressure, Lb.
Hunton	3980	3910	1520
Simpson	4068	4124	1152
First Wilcox	4124	4142	637[a]
Second Wilcox	4217		800[b]

[a] Simpson and First Wilcox open to hole.
[b] Estimated from increase in fluid level.

The formation pressures and the production of four wells for 10 months are shown graphically in Fig. 7. These wells are in South Earlsboro pool, secs. 22 and 23, T.9 N., R.6 E., in Seminole County, Oklahoma. The pool is known to have encroaching edge water forming a natural water flood, the static head of which is the same as the original pressure in the field. Under such conditions it is reasonable to expect the water to have considerable effect on the rate of decline of production and on the formation pressure in the area adjacent to any individual well. If the oil and gas are removed from the reservoir faster than the water encroaches, the formation pressure, and therefore the rate of recovery, will decline as in the first part of the curves for Edwards 2 and Grounds 2. When the production of oil and gas decreases to such a rate that water replaces it at the same rate as it is removed, both the formation pressure and the rate of recovery should be constant, as in Edwards 2 after July, in Grounds 5 after September and throughout Edwards 5. When the flood approaches the well, there will be an increase in the formation pressure and also the rate of production, as in Edwards 2 and Edwards 5 in January. When the water reaches the well, the rate of recovery will decrease and the pressure will remain constant or may increase, as in Grounds 2 after November and Grounds 5 after July. While correlation of the oil production, formation pressures and water encroachment in these wells is obvious, it is probable that if the bottom-hole pressure were available during each of the production tests, a correlation between the pressure differential in the formation and the rate of production would permit a broader and more definite interpretation.

Pierce and Rawlins[1] have determined a mathematical relationship of rate of production and differential pressure within the producing

[1] H. R. Pierce and E. L. Rawlins: The Study of a Fundamental Basis for Controlling and Gauging Natural Gas Wells, Pt. 2. U. S. Bur. Mines *Rept. of Investigations* 2930 (1929).

formation for gas wells. A similar correlation has been found in certain oil wells in the Yates field and in the Seminole district. Moore has given other relations of the rate of production and pressure differentials in the sand.[2] Data on two wells in the Seminole district, worked out according to the method of Pierce and Rawlins, are given in Figs. 8 and 9. The data in Fig. 8 were taken in a well producing from the Wilcox sand where

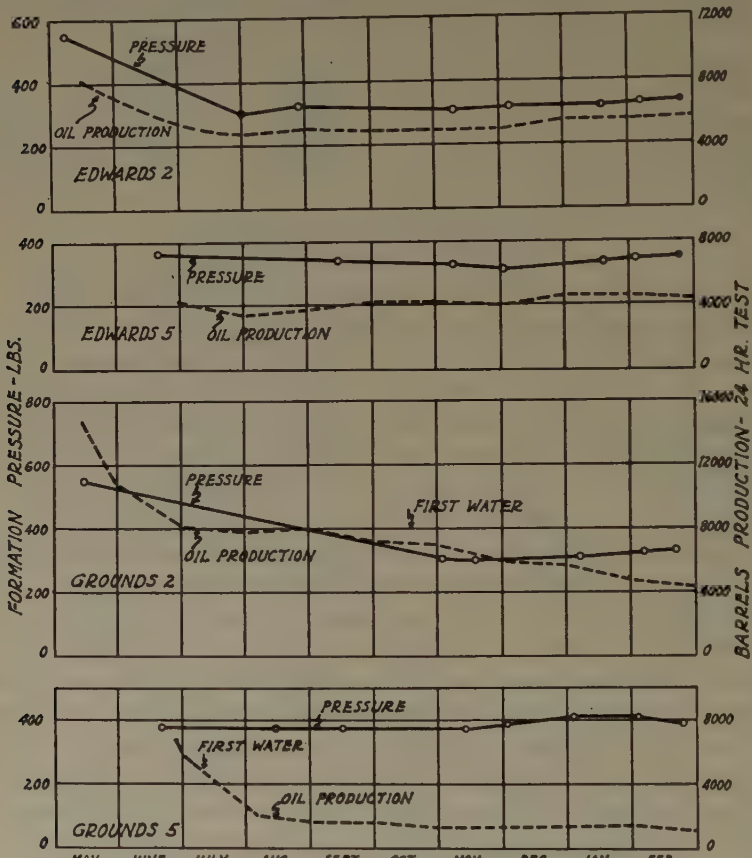

FIG. 7.—RELATIONSHIP OF FORMATION PRESSURE TO RATE OF OIL PRODUCTION. (24-HR. POTENTIAL TEST).

the formation pressure was 412 lb., and in Fig. 9 in a well producing from the Hunton lime in which the formation pressure was 1520 lb. Pierce and Rawlins also found that when this rate of production was expressed by a curve the slope of the curve did not change with depletion. While sufficient data have not been obtained to determine what the effect of

[2] T. V. Moore: Determination of Potential Production of Wells Without Open Flow Tests. Subtopic of Improvement in Production Practice, by W. W. Scott. Amer. Petr. Inst. *Proc.* Eleventh Annual Meeting, Sec. IV, 27.

depletion may have on the correlation in oil wells, it is believed that it may not be so simple as in gas wells. In gas wells the same fluid is

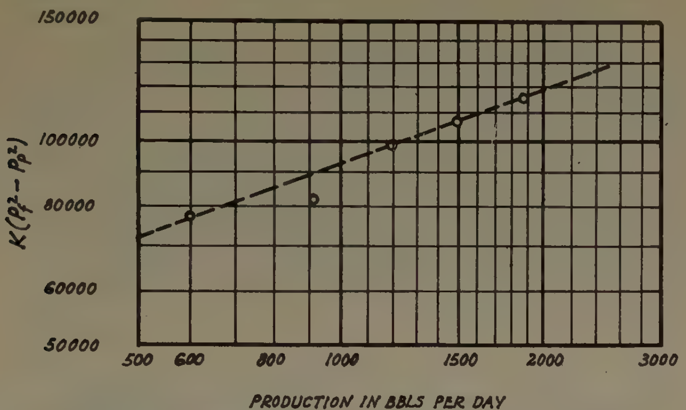

FIG. 8.—RELATIONSHIP BETWEEN FORMATION PRESSURE (P_f) MINUS BOTTOM-HOLE PRESSURE (P_p) AND RATE OF OIL PRODUCTION.

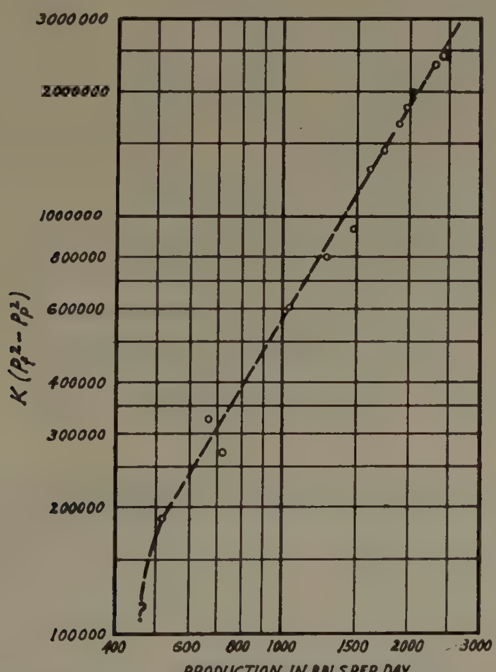

FIG. 9.—RELATIONSHIP BETWEEN FORMATION PRESSURE (P_f) MINUS BOTTOM-HOLE PRESSURE (P_p) AND RATE OF OIL PRODUCTION.

moving through the sand at all stages of depletion while in oil wells the characteristics of the fluid change as the production is depleted, principally due to a change in the absolute gas-oil ratio. Other differences of

lesser importance, such as change in gravity of oil and gravity of gas, including that due to some of the lower hydrocarbons which were originally in liquid state becoming gas, and change of size of drainage channels due to erosion within the producing formation, may affect the correlation after some depletion has occurred. Even though the slope is changed, a correlation should still exist which can be expressed mathematically, but it will require more tests to determine than if the slope should remain constant. The application of this relationship in prorated fields should be especially important. Potential production might be established without opening any well to its open-flow capacity. This would save gas and extra labor and lessen the danger of bringing in bottom water. It deserves much attention in this connection.

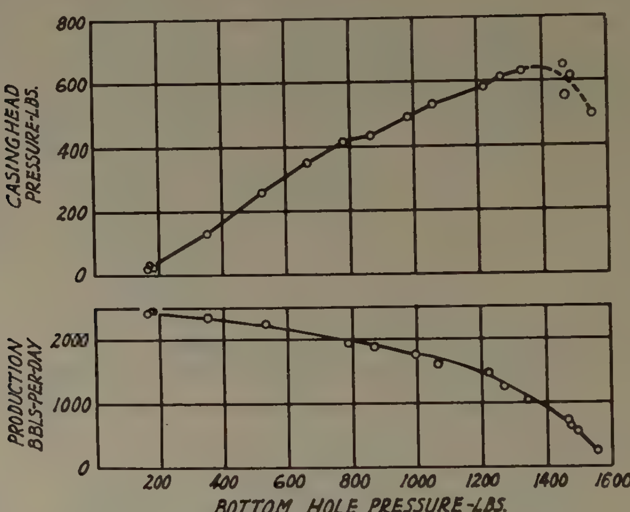

FIG. 10.—CORRELATION OF BOTTOM-HOLE PRESSURE, RATE OF PRODUCTION AND CASINGHEAD PRESSURE.

The relation of rate of production, casinghead pressure and bottom-hole pressure obtained from a series of tests at various rates of production are shown by curves in Fig. 10. These tests were taken from a well producing from the Hunton lime in the Carr City pool, Seminole County, Oklahoma. They were made over a period of about two weeks, and were taken at random, rather than in the sequence of the plotted points. The pressure in the producing formation did not change any measurable amount during this period. Subsequent tests have not given the uniform relationship of casinghead pressure with bottom-hole pressures and rate of production that was obtained in this series. Similar data on a number of wells have shown that the correlation between the casinghead pressure and bottom-hole pressure is often indefinite and becomes more irregular

as the bottom-hole pressure approaches the pressure in the producing formation.

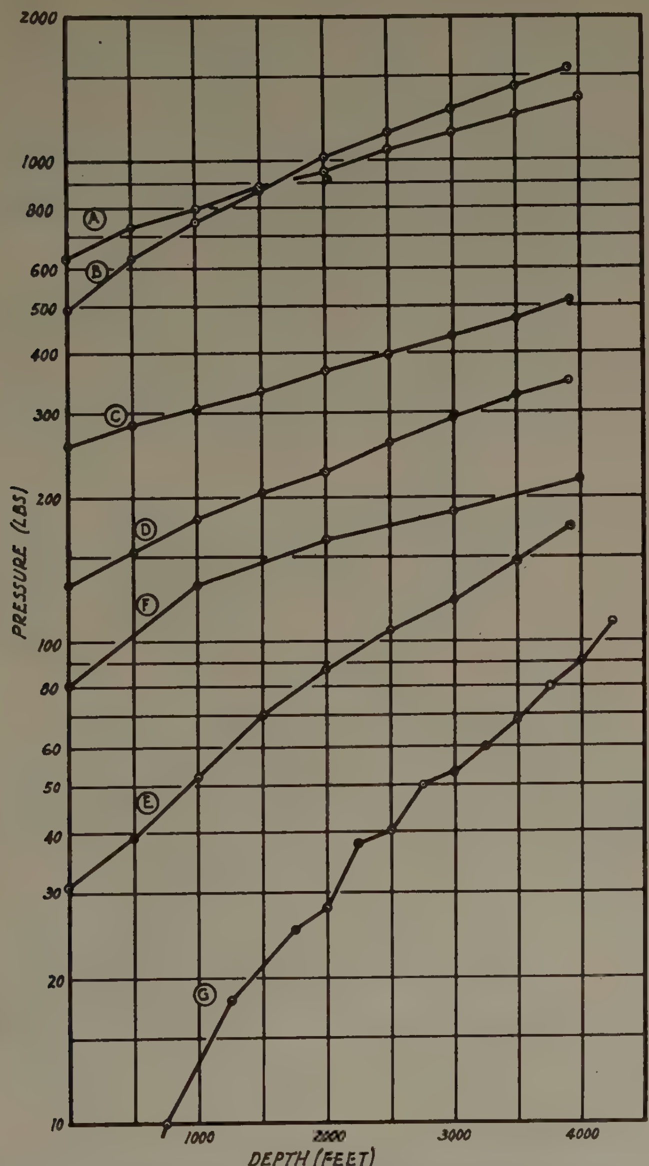

Fig. 11.—Pressures at various depths in flowing wells.

Pressure gradients have been taken in wells flowing naturally and by gas-lift. Some typical gradients are shown in Fig. 11. Additional well data, at the time these pressures were taken, are given in Table 2.

Curves *A*, *B*, *C*, *D* and *E* are on the same well under different pressure conditions. The curves are plotted on semilogarithmic paper and most of the points approach a straight line in the lower part of the flow string, but toward the top of the well there is a tendency for the gradient to become steeper, except in curve *C*. It suggests that the place at which this change occurs may be the place where the flow changes from viscous to turbulent. The velocity at this point probably varies with the absolute gas-oil ratio, because it shows up on the low as well as the high velocities. These curves indicate that the flow of oil and gas mixtures through vertical pipes is probably more regular and the loss in pressure less than is generally considered.

TABLE 2.—*Well Data at Time Gradients Shown in Fig.* 11 *Were Taken*

Curve	Size of Flow String, In.	Absolute Gas-oil Ratio at Top of Well, Cu. Ft. per Bbl.	Velocity at Top of Flow String, Ft. per Sec.
A	8⅝	28	1.2
B	8⅝	36	0.4
C	8⅝	68	56.5
D	8⅝	104	81.6
E	8⅝	669	35.3
F	7	1065	141.5
G	5$\frac{3}{16}$	1420	94.4

Bottom-hole pressures have been taken in pumping wells under operating conditions by placing the gage in a perforated anchor below the standing valve. The chart obtained in one of these wells is reproduced in Fig. 6. This well had been shut down for over 24 hr. at the time this chart started and the pressure recorded was 53 lb., which is considered as the formation pressure. After pumping 5 hr. the pressure decreased to 30 lb., which is 66 per cent. of the formation pressure (absolute). The pressure did not change during the rest of the period of the chart (33 hr.). During this time production averaged 16 bbl. per hour. Another well had a formation pressure of 69 lb., and pumped 27½ bbl. per hour, with a bottom-hole pressure of 56 lb., which is 84 per cent. of the formation pressure (absolute). It is probable that the amount of oil pumped from each of these wells was limited by the capacity of the pump, as it is unlikely that the maximum amount of oil was delivered to either well with so low a differential pressure in the formation. A knowledge of bottom-hole pressures in pumping wells will give as much information for solving recovery problems as in flowing wells. It will also show whether the rate of production obtained is limited by the capacity of the pump or by the capacity of the sand to deliver oil to the well.

Summary

Production control and lifting procedure can be more intelligently directed when bottom-hole pressures and pressures within the producing formation are known. By comparing these pressures the operator may determine whether the rate of production being obtained is limited by the capacity of the method of lifting the oil or by the capacity of the well to produce. The best size of flow string for a well flowing naturally or by gas-lift must be determined by the use of an estimated, calculated or measured bottom-hole pressure, and the degree of accuracy is in proportion to the accuracy of the bottom-hole pressure upon which the calculation is based. Production control used to obtain more efficient use of the gas energy accompanying the oil, to retard bottom water invasion, or to obtain more effective natural water flood, is usually accomplished by regulating the pressure at the casinghead or changing the operating method. These are indirect methods because a change in the rate of production is a result of change in the bottom-hole pressure (more specifically a change in the differential pressure between the producing formation and the bottom of the hole) caused by a change of the casinghead pressure or method of operation. Reliable pressures at the bottom of oil wells and in the producing formation are essential in solving problems of lifting and recovery of oil.

Bottom-hole Beans—Theory, Methods and Effects of Their Use

By William A. Clark,* Santa Fe Springs, Calif.

(Los Angeles Meeting, October, 1930)

A bean placed at the bottom of tubing in flowing wells is not a new idea. In fact, a device which in effect was a bottom bean was patented prior to 1890 by John D. Rockefeller. Because of the limited use of the bottom bean, prior to 1922, when it was installed in a few wells in the Santa Fe Springs field, California, the knowledge of the results of its operation is very meager. Since then various oil operators have experimented with bottom beans, but most of the records of the results obtained by their use are unavailable. For the past year or two, more attention has been directed to this method of producing wells; the theory and best means of application have been studied, and accurate records maintained.

In theory, the use of bottom beans in flowing or gas-lift wells should secure certain advantageous results. With the exception of flow friction of the tubing and flow lines, there is no back-pressure held on the rising column of fluid. Thus severe beaning is possible with no danger of killing the well by too heavy a fluid column, a condition that often exists when a surface bean is used.

The whole energy of the gas expanding to atmospheric pressure is utilized to lift the fluid in the well. The same effect is obtained when flowing a well through open tubing or casing. In using a surface bean this energy of expanding gas is wasted into the flow lines beyond the bean, because the fluid has reached the surface by the time the restriction is reached and the work of the gas performed. The bottom bean affords an efficient use of the expanding force of gas, utilizing less gas to raise the same amount of oil, hence allowing for lower gas-oil ratios.

The flow restriction being at the entrance to the flow string, a more uniform mixture of gas and oil enters the tubing and a steadier back-pressure is held on the well. The uniform mixture and high velocity attained while flowing through the bean, which is above the critical velocity required to suspend a spray condition of gas and oil, prevent slippage of gas, surging and heading with its resultant strain on the casing.

The advantageous conditions allow positive control of production in gas-lift wells within limits set by the bean size and amount of input gas; and probably help to prevent sanding up of a well and the coning

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action of edge-water encroachment. They should also considerably prolong the flowing period of a well at a more even rate.

The relation of the area of the orifice of a bottom bean to that of a surface bean for the same pressure drop may be calculated roughly. The orifice meter formula is $Q = C\sqrt{HP}$, from which we derive Q^2/P varies as H, dropping the constant C. With constant pressure the volume Q is directly proportional to velocity V, so that we can substitute V for Q. If we assume P as constant, V^2 varies directly as H. Also, from the orifice formula, the density or specific gravity varies as H. This is illustrated as follows: A well flowing 535 bbl. per day of oil, 600,000 cu. ft. of gas through a 1-in. bean, under pressures of 265 and 55 lb., has a gas-oil ratio of 1120 cu. ft. per barrel at atmospheric pressure, and a volumetric ratio of 262 cu. ft. per barrel at the flow pressure of 55 lb. The unit of mixture is 262 cu. ft. of gas and 1 bbl. of oil. This unit has a weight and density or specific gravity of 316 lb. and 1.22 lb. per cubic foot, respectively. Now, at a pressure of 265 lb. (20 atm.) the same unit weighing 316 lb. is only 56 cu. ft. per barrel, or 1 cu. ft. equals 5.2 lb. The ratio of the density of 1 cu. ft. at 55 lb. to that of 1 cu. ft. at 265 lb. is 1 to 4.25. The ratio of the velocity squared is the same as that of Q^2. The ratio of Q at 20 atm. to Q at 5 atm. is 1 to 4.3. The difference between the two ratios is due to the incompressibility of the oil content of the mixture. It is usually small, on account of the minor importance of the oil content in the volume of the mixture. Since H varies directly with V^2 and with the density, the density practically cancels V, leaving H varies as V. Since the velocity is practically inversely proportional to P, H varies as $1/P$, and the ratio of bottom to surface bean areas for the same pressure drop varies inversely as the pressures existing at these points.

Bottom-hole beans in present use may be classified as follows:

Fixed Class.—Changed only by pulling tubing.

Adjustable Class.—Adjustable by rotating tubing, rods, or moving lines on a yoke.

Replaceable Class.—Changed by pulling and rerunning bean on sand line.

The types of beans in the fixed class are as follows:

1. A bell-shaped funnel screwed into the end of the tubing, the funnel throat having little or no smaller opening than the internal diameter of the tubing.

2. An iron or steel tube 4 to 8 in. long, screwed into the end of the tubing, having an opening the desired diameter of the orifice.

3. A steel cap, screwed on the tubing, having an opening the desired diameter of the orifice.

4. A steel tube, the orifice of which is machined out on the principle of a Venturi flow tube.

In the adjustable class, where the bean size is changed by rotating the tubing, rods, or by moving lines on a yoke, the bottom member of the bean assembly may be anchored by a spring cage or tubing catcher.

In the types that are adjusted by rotating tubing, the tubing is suspended on a flange over a ball race, set above a packing head. In one of this type, using a sliding sleeve, the bottom end of the tubing rotates freely in an anchored sleeve having a dead end. Slots of the same dimension are cut both in the sleeve and in the part of the tubing that is within the sleeve. The centers of the two slots rotate in the same horizontal plane and suitable lugs or stops are provided on the assembly, so that, when the tubing is turned in one direction, the bean is open, and when turned in the opposite direction the bean is closed.

Another type of adjustable bean involves the same principles as the Shaffer surface flow bean. The assembly, consisting of two halves or nipples, is attached to the bottom of the tubing. The upper half carries the needle valve tip, the lower half being open at the bottom through a steel Venturi tube. The two nipples are united by an easily made-up screw joint, tight enough to exclude fluid but free enough to allow the tubing to rotate and so adjust the valve tip in relation with its seat in the Venturi tube to give any size orifice desired. Still another patented type of adjustable bottom bean consists of two circular steel plates, one anchored by a nipple with tubing catcher, and one welded to the bottom of the tubing. The plates are held firmly together by a bolt and spring. The upper plate has a 1-in. hole; the lower, or anchored, plate has three holes of different diameters which coincide with the hole in the upper plate when the tubing is rotated. While stop lugs determine extreme settings, the adjustment to the two holes between may be largely a matter of guesswork. Some of the other adjustable types use rods within or wire without the tubing in order to change the orifice opening.

In the replaceable class, the bottom bean is changed or adjusted by removing and replacing the assembly on a sand line, without pulling tubing.

One of this type was designed and developed by the Texas Co. It consists of a steel tube from 4 to 6 in. long, containing a bean orifice of Venturi tube type of any desired size, which is screwed into the top of a prepared oil-well pump mandrel. In addition, a 2-ft. section of standing tube is threaded to fit the outside threads of the mandrel, and provides a grip for the small tubing spear used in pulling the assembly. The mandrel containing the bean is seated and locked in a standing valve shoe on the end of the tubing in the same manner as a pump. It is thought that this type of bean is a great improvement over all previous types, on account of the ease and quickness of changing and the positive control of any desired orifice size.

Although not strictly bottom beans, flow nozzles are worthy of mention. Ordinarily, these are not placed at the bottom of the tubing, but at or near the working fluid level, with or without a packer below them. One type is known as the Jarret flow nozzle, designed, probably, for the purpose of utilizing the gas in the casing above the fluid level for lightening the fluid column, or for gas-lift operations, where it was desired to admit the gas into the flow string at a point other than the bottom. The nozzle consists of two nipples, the upper bell-shaped, the lower tubular with a circular shoulder threaded to fit the bottom of the bell member. Gas vents containing ball valves pierce the under part of the shoulder and allow entry of gas into the chamber formed by the inside of the bell, and thence into the flow string.

A flow nozzle of a simpler design than the Jarret was one used in the Torrance field. It was constructed by screwing together the large ends of two bell-shaped nipples. In the shoulder of the lower nipple were six vents tapering downward, to hold simple ball valves. The assembly was placed between two joints of tubing at the desired depth.

Another type of flow nozzle is adjustable, so that the amount of input gas allowed into the tubing can be controlled by turning the tubing. The needle valve, pointing upward, is located in the lower half of the assembly. A by-pass allows the oil to flow past the needle valve up into the tubing. This by-pass has some beaning effect, due to its slight restriction.

The disadvantage of the use of fixed types of bottom beans is that when changing it is necessary to kill naturally flowing wells with mud, always poor practice. Also the lengthy and expensive tube-pulling jobs are objectionable. If the well is killed with oil there is an attendant risk of a blow-out when the tubing is pulled.

The disadvantage of the use of types in the adjustable class is, with some, the small limits of adjustment, and, with all types the guess work generally resorted to in setting a desired bean size, on account of the elasticity of the tubing, rods, or their joints.

The apparent disadvantage of the replaceable type of bean is that it is impractical to change in naturally flowing wells with high pressures and large volumes. In wells of low pressures and small volumes the changing of this type of bean is accomplished either by bleeding the casing or by killing with dead oil.

From information gained by the compilation of a few typical well records, it is evident that the judicious use of bottom beans may often diminish the production of gas in relation to the production of oil, prevent heading and surging, and establish steady pressures, particularly in gas-lift wells. Some data indicate that precipitation of paraffin can be decreased by the reduced heading, but ordinarily the decrease resulting from this effect would be offset by the chilling effect produced by the gas

expanding above the bean in the tubing. Because of the limited use of bottom beans in any one field, no definite statement can be made regarding their effect in controlling edge water or sand troubles.

While conducting an investigation of the results of gas conservation and means of preventing disposition of paraffin in the South Mountain field a few years ago, an experiment with bottom beans was tried on one well. The following tabulation indicates the results obtained on the well over a period of from 15 to 18 days.

Surface Bean	Tubing	Bottom Bean	Daily Oil, Bbl.	Daily Gas, 1000 Cu. Ft.	Ratio
½″	No	No	78.5	640	8150
⅝″	Yes	Sleeve open	78.7	490	6220
No	Yes	Jarret nozzle	81.0	539	6660

The gas-oil ratio was lowered without decrease of oil production. Paraffin deposition was not prevented, but the deposit dropped from its usual position at 1100 to 1350 ft. over a period of two weeks. The test was conducted on but one well and for only a short period. No definite conclusions can be reached because the effect of the tubing run with the beans probably had much to do with the improved results.

In the Torrance field some years ago difficulty was experienced with mud heaving in pumping wells which produced some gas. A flow nozzle was installed, and, probably because the surging effect was eliminated, the mud heaving was partly prevented.

Experiments conducted in another field in California brought out the following results: Five wells (A, B, C, D and E) were selected, four of them at random. Well A was completed through straight tubing with a surface bean only for an initial of 5353 bbl. per day, and 1,844,000 cu. ft. of gas, the ratio being 357. It was killed at the end of the eighth month and a string of tapered tubing with a 1-in. bottom bean was run. The four other wells were completed between the eighth and twelfth months after the completion of well A.

Discussing the above information, well A when first completed without a bottom bean had a continuous rise of gas and consequently an increased gas-oil ratio, while the production of oil declined from an initial of over 5000 bbl. per day to 900 bbl. per day. After killing, installing a 1-in. bottom bean on tapered tubing, and recompleting, the oil production rose and had a more sustained rate of production, while the gas production and ratio declined rapidly, although their curves never dropped below that of the oil-production curve. Wells B, C and D were completed through tapered tubing and ¾-in. bottom beans. Their initial oil production was high and well sustained, the gas production was low,

always declining, consequently their ratios were low. The production curves of gas and oil for these wells were very similar. Oil production of well E compared favorably with that of wells B, C and D, but its gas production was higher and compared with that of well A. It may be significant that this well, although completed with tapered tubing, was not produced through a ¾-in. bottom bean but through a 1-in. bottom bean.

As the above data were taken from but five wells in one field, and were not compared to other wells in the same field without bottom beans, the beneficial results shown may be due in part to the use of tapered tubing.

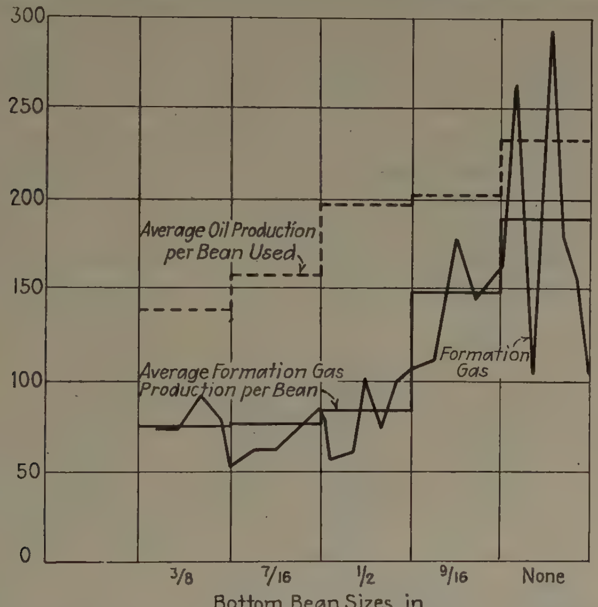

FIG. 1.—RELATION OF AMOUNT OF FORMATION GAS PRODUCED TO EACH SIZE OF BEAN AND TO AVERAGE DAILY OIL PRODUCTION, HUNTINGTON BEACH WELL.

Net gas is so plotted as to correspond to the progressive increase of input gas for each bean. The ½-in. bean is the most efficient size.

It is a question how much of the improved producing conditions can be attributed solely to the bottom beans. It should be mentioned that in order to cut production on the wells for the curtailment program, surface beans had to be placed thereon, the bottom beans being of the fixed type.

Records of results obtained from the use of bottom beans on gas-lift wells are more complete, and from them may be deduced proper methods of beaning wells on the compressor.

The following results were obtained by use of a bottom bean on a gas-lift well at Huntington Beach, California:

This well, with no bottom bean, headed violently every 16 min., and the positive control of production was impossible. A 9/16-in. bean of the replaceable type was installed. Heading ceased and pressures became

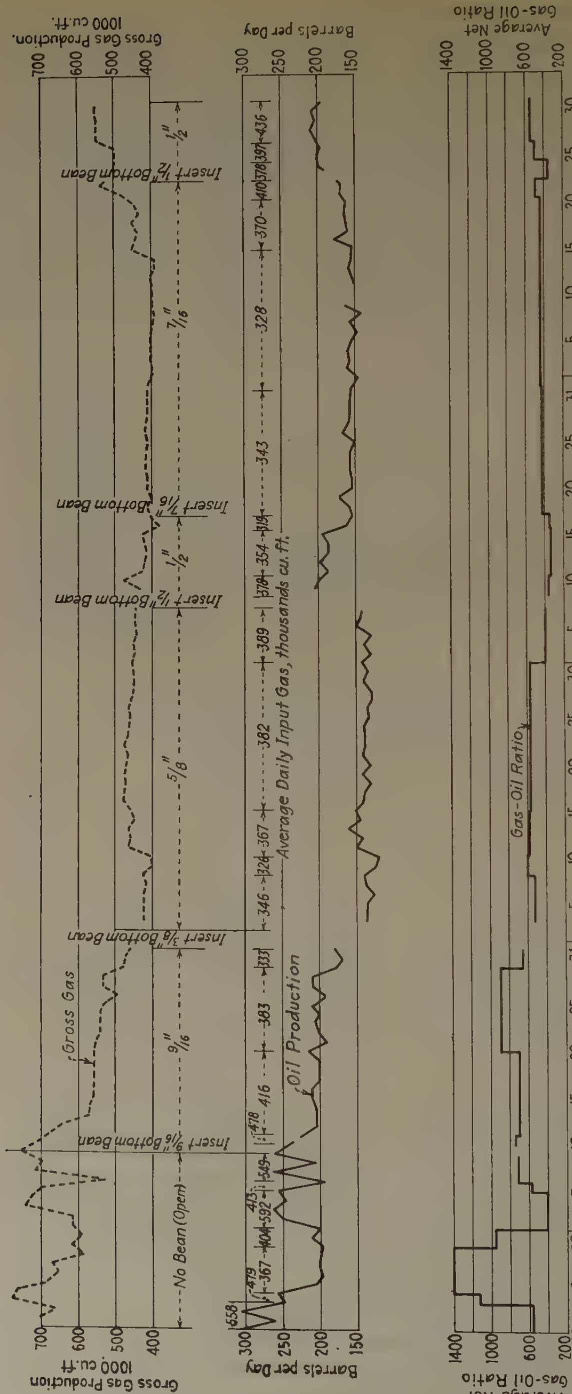

FIG. 2.—GROSS GAS AND OIL PRODUCTION BEFORE AND AFTER INSERTING BOTTOM BEAN, HUNTINGTON BEACH WELL. Note effect on production of varying amount of average daily input gas.

uniform. Production could then be minutely controlled, within limits set by the bean, by varying the amount of input gas.

Controlled by amount of input gas and the bottom beans used there is a range of oil production from 121 bbl. per day to 221 bbl. per day. In each case the production range for each size of bean overlaps that of the next size.

It is apparent that with no bean in the well, production of oil and net gas was little affected by amount of input gas. When using a 3/8-in. bottom bean, the maximum efficiency of lift was reached with 370,000 cu. ft. of input gas. Any increase of input gas above this amount tended to decrease the production. This effect was ably shown on a graph published recently by S. F. Shaw.[1] Fig. 1 indicates that for this well a 1/2-in bean is the most efficient, since it produces a maximum amount of oil with a minimum of input and formation gas. The chart also indicates that the production of net gas is relative to the bean size, not to the amount of input gas.

Fig. 2 shows a curve of four months' production prior and subsequent to installing bottom beans. The curve of gross gas, being steadier than the oil-production curve, clearly shows the changes due to input amount. The change in average oil output is equally definite, however.

Conclusions

In most instances, definite conclusions cannot be established from the meager data available, but the indications are that the use of bottom beans in flowing wells is beneficial for low gas production, sustained oil production and lower gas-oil ratios. In one gas-lift well, the use of replaceable bottom beans resulted in prevention of heading, positive definite control of production, and more efficient and economical operation.

It is hoped that these remarks may promote additional experimentation with bottom beans in conjunction with accurately kept records. There may be some part of a solution here of the problems of excess gas wastage.

Experiments should be made on a bean of the adjustable class that can be accurately and positively adjusted while in the well. Such a bean would be especially applicable to wells flowing from flush high-pressure zones.

Acknowledgment

Acknowledgment is due to V. H. Wilhelm, E. L. Davis and W. E. Remsen for their helpful suggestions and material assistance.

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[1] See page 179.

DISCUSSION

(*V. H. Wilhelm presiding*)

H. N. Marsh,* Los Angeles, Calif.—There seems to be a misunderstanding of the functions and possible value of bottom-hole beans. Beans in general have two purposes: first, to restrict production; second, to stabilize flow. As a means of stabilizing flow the bottom-hole bean may be more satisfactory than the surface bean because it may accomplish that purpose without so greatly reducing rate of production or (in the case of gas-lift) the efficiency. For this purpose it is probably advantageous. If it is desired to restrict production, I see no advantage for the bottom-hole bean, because beaning is a braking process and efficiency is a disadvantage. If increased flow efficiency would automatically decrease gas-oil ratio, it would still be desirable, but unfortunately a decrease of the amount of gas needed to flow a well does not decrease the amount of gas that enters the well. Therefore increased efficiency of the flow string simply requires additional braking effort or bean. These remarks are in no way a criticism of the paper but merely a warning against drawing false conclusions from it.

W. A. Clark.—Referring to Fig. 5 of the paper, I should like to point out that production *was restricted* as well as stabilized, and that the gas-oil ratio was decreased after the bottom beans were installed.

C. M. Beryle,† Santa Fe Springs, Calif.—What is the effect of the bottom-hole bean in a well that produces considerable water?

W. A. Clark.—The bottom beans we are using are of the tapered-tube (Venturi) type and not the straight tube, which prevents turbulence to a great degree and probably does not make a tight emulsion, as a straight one would.

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* Production Engineer, General Petroleum Corporation of California.
† Standard Oil Co.

Density of Oil-gas Columns from Well Data

By William Victor Vietti,* Wink, Texas

(Tulsa Meeting, October, 1930)

Actual field data from several wells are used to illustrate the application of the method of determining the average density of the fluid column in a flowing oil well in the Yates field, Pecos County, Texas.

The depths of the wells in the Yates field vary from 900 to 1700 ft., depending on surface elevation and the location of the wells on structure. Production rates over 8000 bbl. per hour have been determined and many

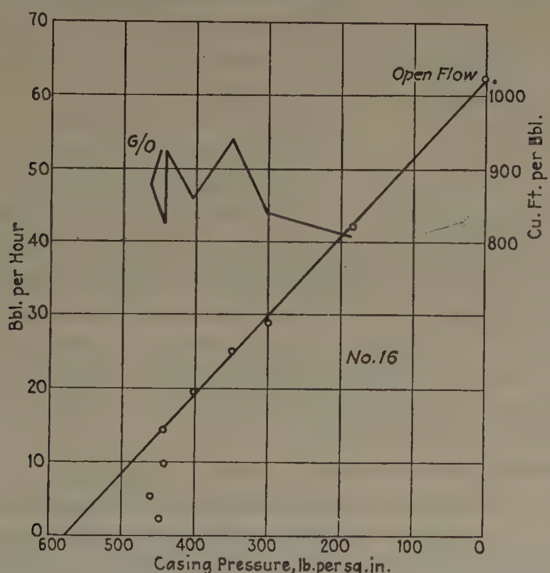

Fig. 1.—Method of determining pressure exerted by column of oil and gas at zero flow.

wells are capable of producing 2000 bbl. hourly. Gas-oil ratios are usually below 400 cu. ft. per barrel, but a few wells high on structure have produced over 3000 cu. ft. per barrel. Incidentally, tubing wells has cut these high ratios to as low as 400 cu. ft.[1] By common agreement of the operators all wells making ratios over 400 cu. ft. will be tubed. Daily production of the field is prorated to 110,000 bbl. from an open-flow potential of 5,000,000 bbl. based on hourly open-flow gages.

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* Petroleum Engineer, The Texas Co.

[1] H. H. Hardison: Effects of Tubing Flowing Oil Wells. Galveston Meeting, A. P. I., Sept. 4, 1930.

The bottom-hole pressure has been determined to be 700 lb. per sq. in. gage.

Characteristic production curves for two of these wells are presented in Figs. 1 and 2. The hourly production and the gas-oil ratio are plotted against casinghead pressures. The points, excepting for very small flows, lie in a straight line. The extension of this straight line to zero pressure will give us an accurate estimate of the open flow of the well with all back-pressure removed.[2] This system of obtaining open-flow potentials without actual open-flow tests has been proposed to the operators in the Yates field.

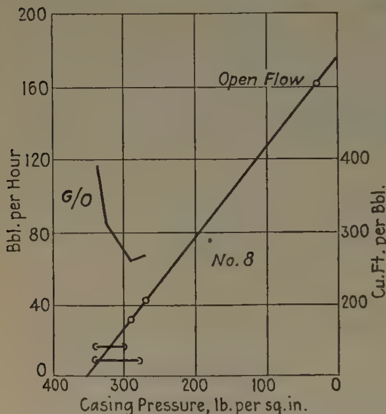

FIG. 2.—METHOD OF DETERMINING PRESSURE EXERTED BY COLUMN OF OIL AND GAS AT ZERO FLOW.

Extending the straight lines in Figs. 1 and 2 in the opposite direction to zero flow gives us a pressure value at zero flow. This pressure is interpreted to be the residual pressure after the pressure exerted by the fluid column is subtracted from the rock or bottom-hole pressure. This pressure is much more significant than a closed-in pressure, for the fluid column has not separated into its component parts, oil and gas, and the value is automatically corrected to zero flow, zero friction and zero work performed on the fluid column. The use of extrapolated values as employed in this method is in general use in engineering and scientific work and is considered applicable in this case.

The subtraction of the shut-in pressure thus found from the measured rock pressure of 700 lb. per sq. in. gives us the pressure exerted by the fluid column (X pressure). Some error is involved by the fact that flow starts somewhere back in the formation and not at measurable points such as the top of the pay or bottom of the hole. Dividing the weight of the fluid column by the distance to the point of entry to the well bore gives us the average weight per foot of the fluid column. The average density of the column can then be calculated. These were calculated on the distance to the top of the first flowing zone and the total depth of the wells.

The data from Figs. 1 and 2 are presented in Table 1; also a summary of the data used and results obtained. Some of these values are obtained from the same well by reason of different trends in different

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[2] Yates Pool Committee Proposes Proration Method Based on Rock Pressure. *Petr. Engr.* (January, 1930) **1**, 46.

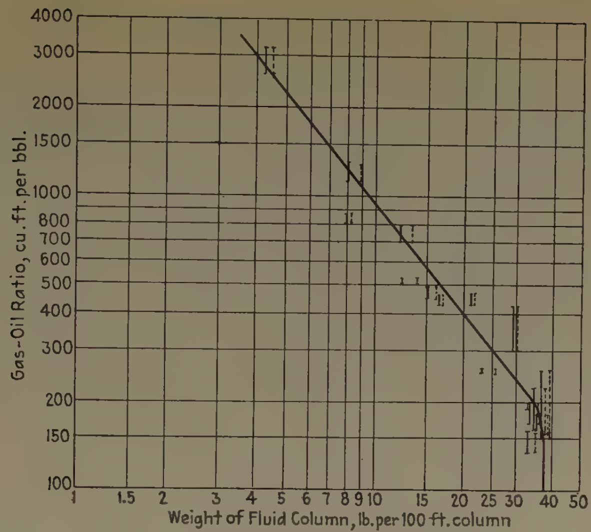

FIG. 3.—WEIGHT OF FLUID COLUMNS OF VARYING GAS-OIL RATIOS.

TABLE 1.—*Summary of Well Data*

Well No.	Oil-gas Ratios	Top Pay	Total Depth	Zero Flow Pressure	× Pressure	Calculated Pressure, Lb. per Sq. In. per 100 Ft.		Calculated Density	
						Top Pay	Total Depth	Top Pay	Total Depth
	DATA FROM FIGS. 1 AND 2								
2	810– 940	1435	1510	580	120			0.193	0.183
8	250– 262	1316	1455	355	345			0.606	0.547
	SUMMARY OF DATA USED AND RESULTS OBTAINED								
1	156– 165	1327	1482	180	520	39.2	35.1		
2	150– 260	1280	1367	200	500	39.05	36.6		
3	162– 185	1255	1388	210	490	39.1	35.35		
4	170– 200	1285	1400	230	470	36.6	33.6		
5	193– 200	1295	1400	230	470	37.2	33.6		
6	160– 225	1235	1330	230	470	38.05	35.1		
7	145– 160	1235	1330	260	440	35.65	33.1		
8	250– 262	1316	1455	355	345	26.25	23.7		
9	300– 430	1030	1050	390	310	30.5	29.6		
10	450– 500	1445	1535	465	235	16.27	15.13		
11	700– 800	1675	1844	475	225	13.44	12.20		
12	430– 470	1020	1055	475	225	21.85	21.3		
13	430– 470	1030	1055	525	175	17.0	16.6		
14	510– 530	1145	1290	540	160	13.98	12.40		
15	1150–1300	1675	1844	550	150	8.95	8.13		
16	810– 940	1435	1510	580	120	8.35	7.94		
17	2590–3240	1300	1340	643	57	4.49	4.26		

ranges of gas-oil ratios, thus allowing the estimation of the several values on one well; *i. e.*, Nos. 6 and 7; 8, 9 and 13; 11 and 15.

The last two columns of pressures in Table 1 are plotted against the gas-oil ratios in Fig. 3 to obtain an average line. This line is terminated at the lower end by the specific gravity of the oil and the upper limit would be determined by the specific gravity of the gas.

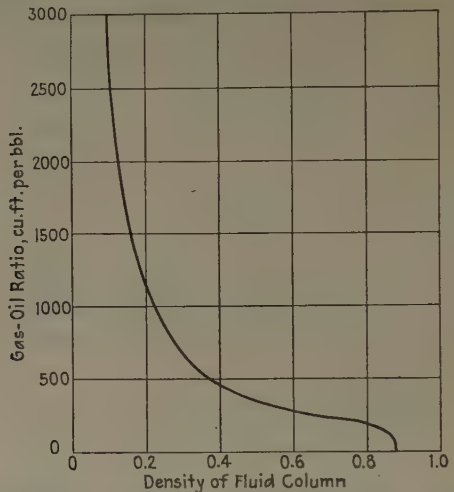

FIG. 4.—AVERAGE DENSITY OF GAS-OIL COLUMNS IN YATES FIELD, PECOS COUNTY.

The average values found are tabulated in Table 2 and presented in Fig. 4.

TABLE 2.—*Density of Oil-gas Columns*

Gas-oil Ratio, Cu. Ft. per Bbl.	Pressure, Lb. per Sq. In. per 100 Ft. Fluid	Density	Per Cent. of Oil Density
00	37.9	0.875	100
100	37.9	0.875	100
200	35	0.808	92.3
250	29.2	0.675	77
300	25	0.576	66
400	20	0.461	52.8
500	16.7	0.386	44
600	14.5	0.335	38.2
700	12.8	0.296	33.8
800	11.5	0.266	30.4
900	10.5	0.243	27.8
1000	9.6	0.222	25.4
1200	8.3	0.192	22
1500	6.9	0.159	18.2
2000	5.5	0.127	14.5
2500	4.55	0.105	12
3000	3.95	0.091	10.4

The data show that between 100 and 200 cu. ft. of gas remain in solution in the oil under pressures of 470 to 520 lb. with very small density changes. A new curve will be found as the rock pressures decrease and less gas is kept in solution in the fluid underground. Similarly, a lower density would be expected were the gas-lift installed, as the gas would be in the free state at the bottom of the hole instead of in solution, as at present.

Data of this type should be of value in planning gas-lift installations and in estimating bottom-hole pressures. Each field will have its own average density curve, dependent on the depth and nature of the producing formation and the quality of the oil and gas. This method is presented in the expectation that future development and application will make it an active aid in the production of oil and gas.

DISCUSSION

(*W. K. Whiteford presiding*)

T. V. Moore,* Houston, Tex.—Dr. Vietti says that the friction losses in the lime in the Yates pool are negligible. I believe one of the curves shown was made from data taken from Humble-Smith A2. On that well, we have found that the friction losses in the formation will amount to 300 lb. per square inch or more. This shows that friction losses in the formation are very important.

Usually, a curve of well-head pressures against production is approximately a straight line at the higher rates of flow. This curve can be extrapolated to zero well-head pressure in order to determine the production under open flow, but I do not quite see Dr. Vietti's reason for drawing a straight line through this curve at the lower rates of flow. It can be shown that this curve passes through a maximum point at fairly low rates of production and at lower rates will fall off markedly. This type of curve has been observed not only in lime fields but also in fields where the production is taken from unconsolidated sands. Thus, it does not seem to be justifiable to assume that the curve of well-head pressures against production is a straight line at all rates of flow. Experimental work which we have carried on with the gas-lift shows that the average density of a column of oil and gas is dependent as much on the quantity of gas flowing as on the gas-oil ratio. At lower rates of flow, the density of the oil-gas mixture approaches that of the liquid, while at the higher rates the density of the mixture falls off markedly. Therefore, the density depends not alone on gas-oil ratio but also on rate of production.

W. V. Vietti.—Mr. Moore's arguments are valid inasmuch as the rate of flow does affect the average density of the fluid column. Low rates of flow occur when high back-pressures are applied. Friction and work are at a minimum; the high pressure causes the oil to retain most of the gas and thus the density of the column approaches that of gas-free oil. Movement of the fluid column is slight and gravity separation of gas and oil occurs. Under higher rates of flow, it is taken for granted that the fluid at the bottom of the column contains little or no free gas, and that the free gas content increases as the fluid nears the top of the hole.

The extrapolation of the straight line back to zero flow does not assume that a well will flow with straight-line characteristics in this region of flow. Friction and

* Production Research Engineer, Humble Oil & Refining Co.

work cause decreases in well-head pressures as the rate of flow increases. The pressure drop increases as the rate of flow increases and the backward extrapolation of the line was made with the thought of estimating the density of the fluid column under steady flowing conditions. No reference is made to the line or densities being valid for low rates of flow under high back-pressures.

The formation in the Yates field is tubular in character and the flow through the formation is more or less of the same nature as that through the flow string. There are two errors in the method presented: (1) We do not know the average distance to the point of fluid entry; (2) the well fluid contains much gas in solution under back-pressure. There are errors involved but I do not believe that the method is vitiated by the values actually found under low rates of flow where the back-pressure is keeping practically all of the gas in solution; gravitational separation is occurring and erratic conditions exist. Under these conditions, the density of the fluid column approaches that of the oil.

T. V. Moore.—There is a very definite reason why that curve passes through a maximum. Pressure losses in the sand increase regularly with production rate. Pressure losses in the flow string at low production rates tend to decrease as production is increased. At higher production rates, friction losses become more important and the pressure losses in the flow string increase with increase in production because the increased friction losses offset the lightening of the column of fluid. The sum of the pressure losses in the flow string and the pressure losses in the sand is, of course, the combined pressure losses from the interior of the reservoir to the well head. It is readily seen that this curve passes through a minimum point which corresponds to the maximum point on the curve of well-head pressure. This is the reason why the curve of well-head pressures rises to a maximum and then falls off.

Velocity of Flow through Tubing

By E. L. Davis,* Los Angeles, Calif.

(Tulsa Meeting and Los Angeles Meeting, October, 1930)

There have been many attempts to devise formulas for flowing efficiency and flow friction of oil-gas mixtures in oil-well flow tubes. Actually, however, flowing efficiency is rarely any real concern of the oil producer and flow-friction formulas contain so many unknown variables as to be of little, if any value.

The production engineer is generally concerned with producing as much oil as possible with a minimum expense per barrel, and with the lowest possible net gas-oil ratio. These ends frequently are opposed to each other and the gas-oil ratio usually is sacrificed. In competitive operations, such as in town-lot fields, high current production is the sole interest.

In conservative operation the greatest possible amount of oil obviously should be produced by natural flow unless the net formation gas-oil ratio can be improved by circulating gas. In practice this condition frequently exists. It would be a great advantage if the flowing condition of a well could be analyzed to determine the best possible producing status. Anticipating the death of a well so that gas-lift could be started immediately after the death, or preferably before, would save both production and expense. Frequently it happens that circulating gas fails to help a flowing well, or will not flow it after it has stopped flowing naturally. A knowledge of the laws governing flow would save considerable expense in testing such cases. A predetermination of probable pressures and amounts of circulating gas needed to flow wells and give best possible producing conditions would help in designing compressor installations.

The optimum producing status of an oil well generally may be obtained by the conditions that subject the producing formations to the least possible back-pressure. This pressure is made up of the weight of the fluid column, frictional resistance to flow and the reaction from the acceleration of the fluid mass. A mathematical calculation of these components to arrive at a condition giving a minimum summation is impractical. Formulas would be complex and the results untrustworthy because it is impossible to assign proper values to the many variables involved.

* Production Engineer, The Texas Co. (California).

However, many of the variables involved in flowing through tubing are functions of the velocity. They include flow friction, acceleration and the power of the flowing gas to hold an oil spray in suspension. The flow velocities of the oil-gas mixture, therefore, should have considerable significance.

Study of Flow Velocities

To attempt to determine optimum and critical conditions, a study of flowing velocities was begun. By "optimum" as used here is meant the lowest velocity or smallest amount of circulating gas necessary to produce maximum fluid. By "critical" is meant the point where continuous flow gives way to severe heading or cessation of flow.

To facilitate this study a nomographic chart was prepared for calculating the flow velocity at the base of the flow tube or any other point where the pressure is known (Fig. 1). The formula upon which the chart is based is as follows:

$$\frac{\dfrac{\text{Cu. ft. gas per sec.}}{\text{Pressure in atmospheres}} \text{ plus oil, cu. ft. per sec.}}{\text{Capacity of linear ft. flow tube in cu. ft.}} = \text{Velocity ft. per sec.}$$

The chart is graduated in the familiar 1000 cu. ft. per day, barrels per day, pounds per square inch and actual and nominal diameters of flow tubes. The scales used are selected to absorb all conversion constants.

The chart as shown is not corrected for compaction due to the weight of gas in the casing. This may create a pressure at the shoe as much as 200 lb. or more, greater than the recorded casing pressure in very deep wells with high casing pressure. Nor is it corrected for solubility of gas, which introduces a large correction for high-pressure wells with low gas-oil ratios; nor for loss of head due to friction in descending circulated gas; nor for correction due to changes in temperature, or deviation from Boyle's law. These factors are all computable and should be introduced in order to get really accurate results. However, extreme accuracy is probably not justified in the results, especially in a preliminary study, and since only relative values were desired the calculations were made from the chart alone.

The chart is easy to use and calculations may be made quickly. In the problem shown on the chart, a well producing 900 bbl. per day and 700,000 cu. ft. of gas with a casing pressure of 720 lb. is illustrated. A line between 700 on the Q scale and 720 on the P scale intersects the S scale at 14. On the B scale 900 bbl. is read as 5 M. cu. ft. and added to 14 on the S scale, making 19. A line between 19 (S_B) and 2½-in. tubing on the D scale intersects the V scale at 6.8, which is the desired tubing shoe velocity in feet per second.

The tabulation of tests shows 12 cases where critical velocities in flow tubes were determined. In all but two cases, both of which were the same well under different conditions, values of the critical velocity ranged from 4.3 to 7.7 ft. per second. This is far below the theoretical velocity

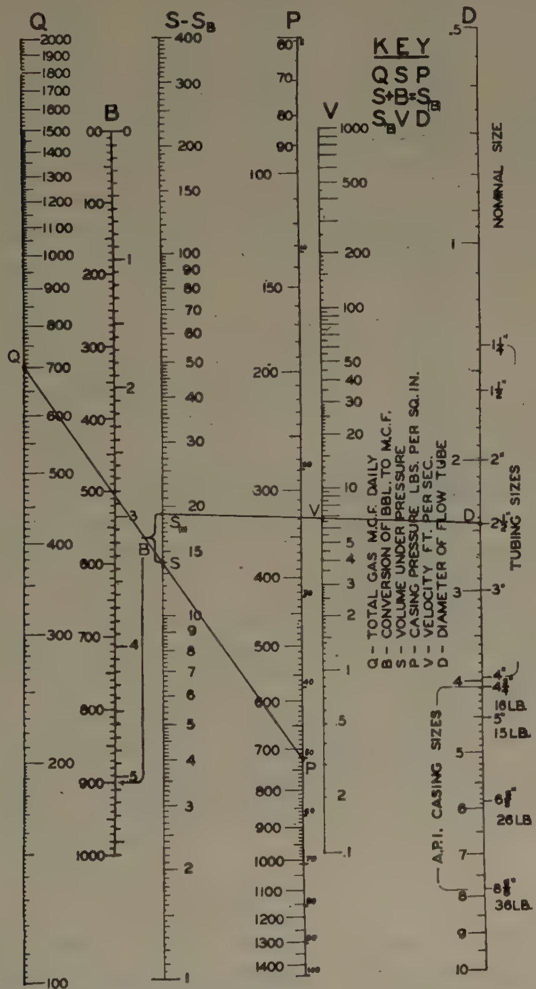

Fig. 1.—Flow velocities of gas-oil mixtures.

for suspension of oil mist in gas,[1] but no actual case of higher critical velocity was found. The cases where 1.4 and 2.6 were determined as critical velocities were where the "volumetric gas-oil ratio under pressure" shows that the gas-oil mixture probably existed as a foamy liquid

[1] P. Lenard: Ueber Regen. *Meteorologische Ztsch.* (1904) **21**, 249–262.

TABLE 1.—*Flowing Conditions of Wells*

Well Numbers	1	1-A	2	2-A	3	4	5	6	7	7-A	8	9	10	11	12	13
Depth of well, ft	6850	6850	6825	6825	7125	6900	8000	7800	6850	6850	6800	6800	3000	6500	7255	7950
Size of casing, in	5	5	5 with 3 liner	5 with 3 liner	5	5	5 with 3 liner	5	5	5	5	4¾	6⅝	5¾	5¾ with 3 liner	6⅝ with 5 liner
Top of perforations, ft	6290	6290	6275	6275	6265	6370	7680	7780	6326	6326	6250	6300	2800	5479	5725	7475
Depth of flow tube, ft	6250	6250	Casing	6280	6233	6600	7560	7000	Casing	Casing	6200	6300	2800	6000	6280	7250
Size of flow tube, in	2½	2½	5 & 3	2½ & 1½	2½	2½	2½	2½	Top of Perfs., 6300	Top of Perfs., 6100	2½	4¾	3	2½	2½	3
Critical Conditions																
Gross oil, bbl. per day	800	950	680			370	30	135	1090	1460			720	137	62	175
Gross gas, M. cu. ft. per day	560	475	450			500	400	200	400	780			580	380	350	490
Gross gas-oil ratio	700	500	660			1350	13300	1480	367	540			805	2770	5620	2810
Net gas, M. cu. ft. per day	560	100	450			300	100	200	400	120			200	380	350	490
Net gas-oil ratio	700	105	660				3333	1480	367	82			278	2770	5620	2810
Casing pressure, lb. per square inch	700	720	500			475	300	250	800	700			270	400	225	250
Tubing-shoe velocity	5.7	5.2	1.65 & 4.83			6.0	6.7	4.3	1.4	2.6			7.7	5.0	7.6	6.5
Velocity in casing below tubing	1.65	0.75	1.65 & 4.83				1.12	1.25	1.4	1.1			.9	1.1	1.8	1.75(6⅝")
Volumetric gas-oil ratio under Pressure — gross	2.56	1.78	3.3			7.2	150.9	15.3	1.18	1.97			7.4	17.7	61.1	28.2
Volumetric gas-oil ratio under Pressure — net	2.56	0.375	3.3			7.2	27.6	15.3	1.18	.305			1.5	17.7	61.1	28.2
Optimum Conditions																
Barrels oil per day		1350		610	190	475	70	130			300	370				
Gross M. cu. ft. per day		1400		720	700	930	745	525			840	1060				
Gas-oil ratio		1070		1180	3680	1960	10600	4030			2800	2870				
Casing pressure		610		410	240	400	200	250			260	300				
Tubing-shoe velocity		14.0		10 & 22	14.5	12.5	18.5	9.5			16.5	6.5				

rather than a gas-laden mist. In this condition the velocities found should be adequate to prevent flow-tube slippage. The data show that except in cases such as the above, minimum flow velocities of less than 8 ft. per second should be avoided.

The determination of optimum velocities was less definite. Values of shoe velocities from 6.5 to 18.5 were found in eight examples; 15 appears a good average.

Optimum conditions obviously involve variables in a different sort of balance. Here the additional lightening of the fluid column is opposed by added flow friction. Optimum conditions should vary with different sizes of flow tubes. Shoe velocities should be less significant, since velocities would necessarily be above the critical.

The velocities with which maximum oil is produced ordinarily have a rather wide range. Velocities quoted are the minimum at which this amount of fluid is produced.

Both critical and optimum conditions obviously involve factors other than flow-tube velocity. The size of the flow tube, whether flowing through tubing or in the annular space, the relation between the bottom of the flow tube and the producing formation and other variables have an important bearing. In well No. 6, with tubing set at 7000 ft., 800 ft. off bottom, gas flow is continuous but oil is produced only when the well makes a head sufficient to raise fluid up to the bottom of the flow tube. An analysis of the data in Table 1 will suggest what some of the other variables are and give some idea as to their effect.

This paper is intended to be only a preliminary study of the effect of velocity, and tests were limited to the available types of wells. Broader phases of production of flowing wells such as position and size of flow tubes, tapered strings, bottom beans, packers etc., are not considered. This is not done with the idea of minimizing their importance, but simply to restrict the scope of the paper.

The study of flow velocities is believed to yield valuable information and justifies further investigation.

Acknowledgments

The helpful suggestions and material assistance of V. H. Wilhelm and H. C. Stone in the preparation of this paper are gratefully acknowledged.

DISCUSSION*

H. N. Marsh,† Los Angeles, Calif.—Consider a well that has sufficient pressure so that after it has ceased to flow steadily it will still flow intermittently. Do you find the efficiency much lower with intermittent flow than with continuous flow?

E. L. Davis.—We have not found it so.

* W. W. Scott presided at Tulsa; V. H. Wilhelm at Los Angeles.

† Production Engineer, General Petroleum Corporation of California.

T. V. Moore,* Houston, Tex.—In a pipe carrying a mixture of oil and gas, the gas must flow up the pipe at a velocity greater than that at which the liquid flows. It can be easily shown that the equation proposed assumes that the oil and gas flow are at the same linear velocity. This is a serious error. In order to determine the linear velocities of gas and oil, we must know what portion of the pipe is carrying oil and what portion is carrying gas. I fthis is known the velocities of the liquid and gas can be easily determined and I believe the problem of the design of flow strings will then be solved.

H. N. Marsh.—A method of designing flow strings has been in use for several years by my company, which, while not theoretically correct, has given results consistently better than could be secured by haphazard installations. Oil and gas were flowed at different rates and ratios through vertical pipes of various sizes about 40 ft. long. The pressure gradient corresponding to each condition was measured accurately. With this information as a starting point, flow strings are designed in an attempt to give a minimum pressure drop. From the data the proper size of flow string for the top of the hole is selected and from the pressure gradient the pressure, and therefore the gas-oil ratio (on a volume basis) at some arbitrary depth is calculated. From this new ratio the correct size of tubing at that depth is selected and the pressure at the next increment of depth computed. This is repeated until the bottom depth is reached. The method is in error because the tests were made with gas at moderate pressures, and in the design the weight of the gas is neglected and only the volume that it occupies is considered. In spite of this, results are gratifying and check approximately with those predicted.

E. L. Davis.—There was no intention of creating a basically correct formula. The intention was to test whether or not velocity is a fundamental consideration in preventing separation of oil from gas in the flow column. This separating out is considered to be the cause of heading. If velocity is significant, the minimum or critical velocity should be either that at which gas bubbles will rise in oil without raising the oil, or that at which oil droplets will settle in a column of gas. The velocity indicated by the formula is, of course, essentially the velocity of the gas. The formula, admittedly an approximation, was charted to facilitate a preliminary study and at the same time serve a useful purpose in actual producing operations.

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* Production Research Engineer, Humble Oil & Refining Co.

Characteristics of Drilling Fluids

By C. P. Parsons,* Duncan, Okla.

(Tulsa Meeting, October, 1930)

To properly account for the various characteristics of drilling muds obtained in different areas and geological horizons, it is necessary to study the composition of the mud from a chemical and physical standpoint as determined by the proportions and activities of the various solid contituents that are present in various states of division.

Briefly summarized, science teaches that there are three states of division into which these solid constituents or particles may be grouped: namely, the suspended state, the individual particles of which are known as suspensoids; the colloidal state, in which the individual particles are termed colloids; and the crystalloidal state, wherein the individual particles are held in true solution and are termed crystalloids.

The suspended state is one wherein the particles are fairly large and are present as molecular complexes, having none of the properties of colloids or crystalloids. Since matter varies in physical character and in chemical activities with its state of division, these coarser suspensoids do not themselves materially affect the physical or chemical properties of the solution in which they are suspended. On the other hand, they are distinctly detrimental in drilling muds and it is desirable that they be removed. Under the general classification of suspensoids are included sand, gravel and cuttings which contribute nothing to the colloidal stability or other desirable properties of the drilling fluid.

As the state of division approaches but does not reach a molecular simplification, the term "colloidal state" is used in describing this condition. The colloidal state arises when one form of matter is in a very fine state of division and is distributed through a second phase. The material in the finely divided state is called the dispersed phase, while the liquid in which it is dispersed is called the dispersive phase. These particles of matter are in a colloidal state and will not settle out from the dispersive phase so long as colloidal conditions are stable. Moreover, they exhibit the property of having an oscillating movement around a central position in solution (the Brownian movement).

In the third state of division, the crystalloidal state, the individual particles are held in true solution and are usually present as single molecules or ions. In a drilling fluid the water content of the fluid contains

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considerable crystalloidal matter, usually in the form of soluble salts. Solutions of crystalloids have different physical properties in so far as boiling point, vapor pressure, etc., are concerned, from the solvent in which the crystalloids are dissolved.

Colloids, on the other hand, exert very little or no effect on the physical constants of the dispersive medium. Some colloids have absolutely no effect on these properties, while others do possess such influences to some degree, depending on whether the colloidal particles more nearly approach the suspended or crystalloidal states, respectively.

Colloids are very susceptible to coagulation by chemicals, heat and electrolytes and possess great absorptive and adsorptive powers. These properties are extremely important in rotary drilling fluids and present a formidable basis for unlimited study. The latter part of this paper presents some interesting laboratory results along this line.

Properties of Drilling Fluids

One form of flocculation or agglutination of colloidal materials in drilling fluids is due to neutralization of the electric charges which these materials carry. For instance, a clay suspension having negatively charged colloidal particles is flocculated by materials carrying positive charges. Since like charges repel and unlike charges attract, mixed charges vary in stages of neutralization and flocculation. Such properties present possibilities for chemical treatment of rotary drilling fluids whereby thickening or thinning may be obtained by the proper selection and combination of chemical reagents. In addition to the effect of electric charges, there are other influences brought about by adsorption, which can be made to sensitize a colloid so that it may be more easily flocculated (precipitating a gel on the interfaces of the particles) or which may act as a protective agent to retard flocculation and increase the stability of the colloidal suspension.

In drilling fluids we are concerned with colloids having the property of combining with water solutions to form gels. Gel is the general term for a solid or semisolid colloidal state; gelatinous precipitates and jellies being two forms of gels.

A stable colloidal solution, as applied to drilling fluids, consists of very fine solid particles kept from settling by a protecting film or agent, usually either protective colloids or electrolytic action or both; such condition being sufficiently rugged to withstand constantly the severe mechanical agitation and chemical contamination imposed on the fluid while drilling.

When the colloidal state of the solid particles in a drilling fluid is disintegrated by chemical rather than by mechanical or electrical means, this disintegration is called peptization. Certain salts, when picked up by

the drilling fluid from salt water in a well, act to peptize unstable colloids, destroying the forces of cohesion and adhesion.

The formation of gels within a drilling fluid increases the viscosity of the fluid and also contributes to the stability of the suspended particles. In some instances a drilling fluid will be deficient in these gel-forming bodies, hence the solids will settle out freely, while in other instances the

Sample No.	1	2	3	4	5	6
Location of Well	West Columbia, Texas	Pierce Junction, Texas	Van, Texas	Voshell, Kansas	Oklahoma City	Ventura, Calif.
Color	Light brownish gray	Light brownish gray	Gray	Gray	Dark brownish gray	Dark gray
Sp. Gr.	1.205	1.205	1.205	1.205	1.205	1.205
Wt. per Gal.	10 Lb.	10 Lb.	10 Lb.	10 Lb.	10 Lb.	10 Lb.
Litmus Reaction	Slightly basic	Slightly basic	Strongly basic	Slightly basic	Strongly basic	Slightly basic
Viscosity (Water = 1.0)	1.42	1.18	1.47	1.31	1.17	1.14

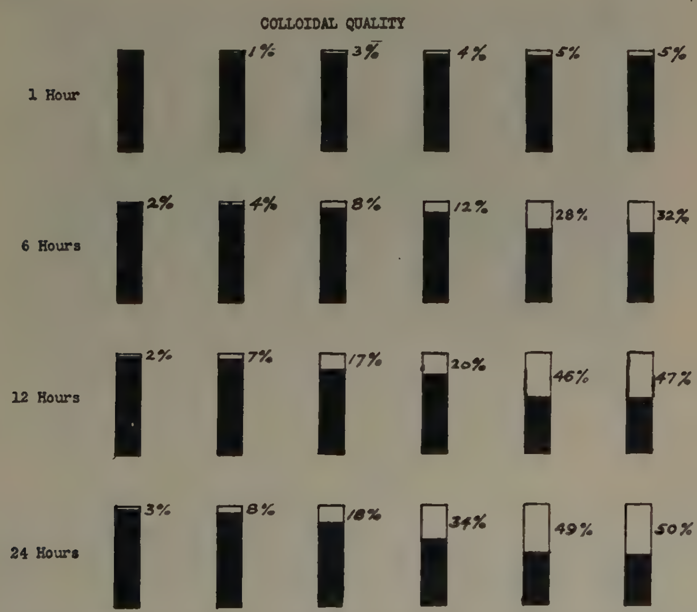

FIG. 1.—CHARACTERISTICS OF SIX SAMPLES OF NATURAL DRILLING FLUIDS TAKEN FROM WELLS IN VARIOUS AREAS.

gel-forming bodies may be present in such large proportions that they make the mud unduly viscous and thereby prevent the settling out of sand and cuttings and the release of occluded gas. Natural muds from different areas vary widely in the proportions of gel-forming bodies they contain, hence have very different characteristics. In general the natural drilling muds of Kansas, Oklahoma and North Texas grade from

suspensoids to medium colloids while Gulf Coast areas yield some very highly colloidal muds at certain horizons. Fig. 1 indicates graphically the colloidal qualities and other characteristics of six samples of drilling fluids obtained in various areas.

Control of Fluid Properties

In some instances it is desirable to increase the gelatinous bodies within a drilling fluid and this is done either by the addition of chemicals which will react with some of the naturally occurring constituents of the mud to form gelatinous bodies, or through the addition of materials that form gels when combined with water.

On the other hand, in the treatment of muds which are unduly viscous, having excessive proportions of colloidal gelatinous bodies, it is necessary to add chemical reagents that will modify the cohesive and adhesive effects within the mud. This applies, of course, when it is desired to keep

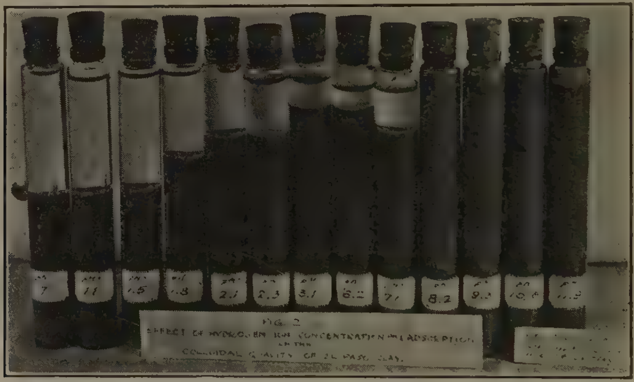

Fig. 2.—Actual effect of both hydrogen ion concentration and adsorption on colloid quality of El Paso clay.

Each sample contains the same amount of clay. The four samples on the right were very thick, owing to adsorption.

the weight constant, and when it might be desirable to decrease the viscosity in order to increase the weight by the addition of weighting material. This will make it possible to decrease the viscosity of the mud to a point where sand, cuttings and occluded gas are more readily released, although the stability of the colloidal suspension is not materially decreased. Accompanying this change in viscosity there would be a decided lightening of the load on the pumps.

In one type of compound (Stabilite) now used in the Gulf Coast area for the chemical treatment of high-viscosity drilling fluids, the viscosity is lowered to allow release of cuttings and prevent gas cutting or for the addition of weighting material, but the colloidal state of the fluid is further stabilized by the presence of a second colloid, which is strongly adsorbed by the clay particles and acts to protect the particles from the influences

tending to cause coagulation or agglutination. It also imparts to the drilling fluid the property of forming a soft gel when the mud is quiet, such as when the drill stem and pumps are stopped. This gelling property acts to prevent sand and cuttings from settling to the bottom of the hole and possibly sticking the drill pipe. Upon being slightly agitated the mud returns to a highly fluid condition, which is easily handled by the pumps.

It is reported[1] that recently in a field south of Beeville, Texas, a well was drilling at about 5500 ft. in a formation that made a thick viscous mud, which, with weighting material, weighed 12 lb. per gallon. A high-pressure gas sand was then penetrated and the mud became gas-cut and threatened to blow out whenever an attempt was made to remove the drill stem. After a number of unsuccessful attempts to remove the drill stem, the mud was treated chemically by a process that thinned it without decreasing the weight of the fluid. This thinning released the occluded gas and then allowed the addition of more weighting material to 14 lb. per gallon. The drill stem was then removed. This illustration is presented to show a phase of the practical side of the subject.

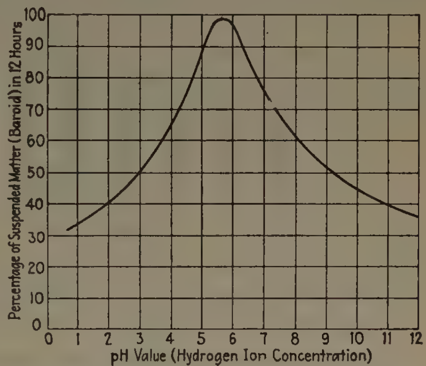

Fig. 3.—Effect of hydrogen ion concentration on colloidal quality of baroid in 12 hr. after agitation.

Mixture contains 25 per cent. baroid, by weight, with water solution of varying hydrogen ion concentration.

In the chemical treatment of a drilling fluid the chief objective is to obtain a colloidally stable fluid of a desired viscosity and weight; the viscosity having a nature of slickness instead of stickiness, which allows a readier release of cuttings, sand and occluded gas.

Effect of Hydrogen Ion Concentration and Adsorption

Theoretically, clay particles reach a state of maximum dispersion in a fluid when alkali is added in sufficient quantities to raise the pH value (hydrogen ion concentration) to above 9. If that condition alone held true, the addition of an alkali to drilling fluids would be expected to thin the mud.

Actually, however, in many natural drilling fluids, the reaction is entirely different. In such cases the addition of alkalies or alkaline salts produces flocculation and increased viscosity. Fig. 2 illustrates this effect on a clay.[2] This effect is due to the presence of soluble metallic

[1] Communication from T. B. Wayne, Chemical Engineer, Houston, Texas.

[2] "El Paso clay," from Findlay, Texas.

salts bordering on a state of true solution in the water content of the drilling fluid, and to the presence of metallic salts in the clay particles. These metallic salts in the mud react through the process of adsorption, with the alkali or alkaline salts added to the mud, forming gelatinous precipitates which actually increase the viscosity of the mud. This is illustrated by the four samples with pH values from 8.2 to 11.9 shown in Fig. 2. At the same time that this secondary reaction occurs, there

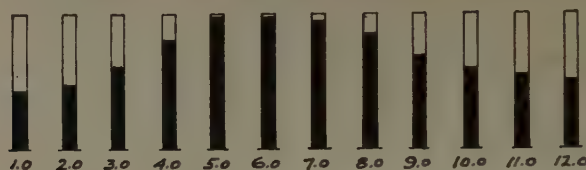

FIG. 4.—SAME EFFECT AS IN FIG. 3 ON BAROID IN 1½ HR. AFTER AGITATION IS STOPPED.

is a deflocculating action which affects the electrolytic condition of the primary colloids, but the net result is increased viscosity. The point of this explanation is that the flocculating or deflocculating actions of alkalies on drilling fluids should be interpreted not only on the basis of change in pH values but also on the basis of chemical changes due to adsorption. Fig. 2 shows the combined effect of hydrogen ion concentration and adsorption on a certain clay while Fig. 5 shows the effect on a

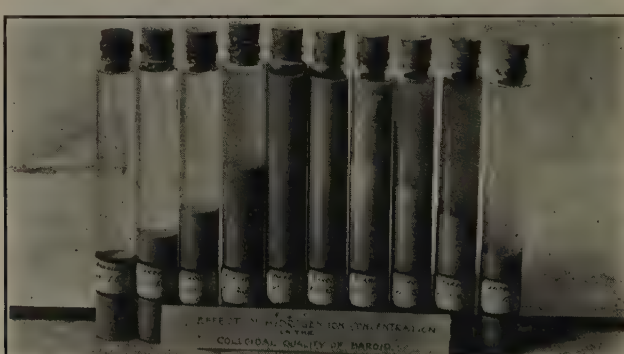

FIG. 5.—ACTUAL EFFECT OF HYDROGEN ION CONCENTRATION ON BAROID.

more inert substance (baroid). In Fig. 5 there is no evidence of adsorption on the barite particles, but the cloudiness of the upper part of the three bottles next to the last one on the right is due to adsorption on the colloidal material that is in baroid. The action of some alkalies and silicates (caustic soda, soda ash, sodium silicate, etc.), which are used in similar problems of other industries, produces some immediate results in changing the viscosity of a drilling fluid, but their use in an uncombined form should be accompanied by an assurance that the surface film of cohe-

sive matter produced is sufficiently stable not to be easily broken down under agitation while drilling, or by the peptizing action of salt waters picked up in the wells. Gels formed by these uncombined alkalies often are of a type subject to "weeping"; *i. e.*, contraction of the gel and liberation of free water.

The special factors in the study of clay suspensions in drilling fluids that are not present in similar problems of other industries, and consequently not covered by precedent, are the highly concentrated and widely varied crystalloidal content of the dispersive phase, and the severe mechanical demand and chemical contamination imposed on the fluid while drilling.

For discussion, see page 250.

Properties and Treatment of Rotary Mud

By Hallan N. Marsh,* Los Angeles, Calif.

(Tulsa Meeting and Los Angeles Meeting, October, 1930)

The subject of mud sounds so simple, uninteresting and unimportant that it has failed to receive the attention that it deserves, at least as applied to the drilling of oil wells. As a matter of fact, it is one of the most complicated, technical, important and interesting subjects in connection with rotary drilling. In 1923, R. E. Collom[1] said "It should be possible to establish certain physical standards for mud fluid," but while considerable work has probably been done on the subject before and since that time, and numerous articles have been written, the progress of general knowledge of the subject and the application of better practices have not kept pace with other developments in rotary drilling, and physical standards cannot be considered as established.

Mud is apt to be thought of as an accessible and cheap material, but its cost is likely to be an important factor in the total cost of drilling a well. Some wells "make" most of their own mud out of the formations drilled, but in most cases a great deal of mud-making material has to be supplied from more or less distant sources. Expenditures for mud materials by one California company totaled practically one-quarter million dollars during 1929 and averaged about $13 per rig per drilling day, or about $2000 per well. Under unfavorable conditions, mud cost may reach many times this figure. Parker[2] says that in the Hobbs, N. M., field "as much as $75,000 has been spent on one well alone for mud and mud-weighting compounds." Presumably this is an exceptional case. Unit cost of mud fluid will range from 10 c. per barrel, where suitable material is close at hand, to $1 where crude material is available at moderate price but must be hauled long distances, and on up to as much as $11 per barrel where high gas pressure requires the use of special processed weighting material.

The cost of mud pales into insignificance, however, when the results of using improper mud are considered. Blow-outs and lost circulation are obviously the result of inadequate mud. Stuck drill pipe, whether or not twisted off, in many if not most cases probably is caused by cuttings settling out of the mud or the mud itself precipitating. Recent experi-

* Production Engineer, General Petroleum Corporation of California.

[1] J. R. Suman: Petroleum Production Methods, Ed. 3, 36. Houston, Texas, 1921. Gulf Publishing Co.

[2] S. S. Parker: The Hobbs Oil Field, New Mexico. *Oil Bull.* (1930) **16**, 717.

ence has demonstrated that rate of wearing out of mud-pump valves, liners, pistons and rods can be reduced enormously by elimination of cuttings from mud.

Aside from the fact that the importance of the selection and care of mud has not been fully appreciated, the slow progress of the subject has undoubtedly been due to the fact that it involves scientific knowledge of colloidal chemistry and physics, familiarity with technical processes most commonly encountered in the ore-dressing industry and practical knowledge of rotary-drilling practice. Undoubtedly there are many chemists to whom the following dissertation will appear superficial and perhaps in some details incorrect, and some practical oil men whose experience will have proved some of the suggestions advanced to be inapplicable. However, it is hoped that a discussion of the subject from a partly theoretical and partly practical point of view will call the attention of the more scientific faction to the nature and importance of the problem, so that they may bring their knowledge to bear on it, and also suggest to the operating personnel theoretical possibilities of which some may prove practical.

Properties of Mud

In the ultimate analysis all properties of muds are the result of, and might be expressed in terms of, the specific gravity, fineness and concentration of the solid particles, and their degree of dispersion as determined by the presence in the water of alkali or acid, emulsifying agents and peptizing agents, which affect the degree and form of dispersion of the solids. However, the effects of these fundamental factors are not well understood even by the colloidal chemist, and much less by the layman. It is therefore convenient to consider the various properties under the following headings, which are of direct significance:

1. Specific gravity or weight per unit volume.
2. Mechanical analysis or fineness of solids.
3. Consistency (viscosity; plasticity; degree, nature and permanency of dispersion).

Weight

It has been customary to judge the quality of a mud largely by its "weight" or "thickness," the two terms being considered more or less synonymous. It may be stated emphatically, however, that weight (specific gravity) and thickness (consistency) are independent properties and must be separately considered. A mud may be heavy enough for all but the most extreme conditions and still be a little thicker than water. On the contrary, a mud so thick that it will not flow in a ditch may be as light or lighter than water, thus permitting blow-outs in territory of moderate pressure. The specific gravity or weight per unit volume

of a mud is a definite and important property. Sufficient weight is required so that hydrostatic head of the mud in the hole will exceed the pressure in the formation being drilled through, and thereby prevent blow-outs.

Weight of mud is commonly determined by weighing a definite volume in a bucket suspended from a spring balance. This method is accurate enough for ordinary purposes if done with sufficient care but is apt to be so far from correct as to be entirely misleading if the work is carelessly done with dirty, rusty or otherwise unsatisfactory balances. A weighing device is now on the market which resembles a hydrometer and comprises a small mud-sample cup with cover which is hung on a calibrated float in water. The weight or specific gravity of the mud is read directly on the float. This is convenient and accurate if used intelligently. The water in which it is used must be nearly at standard temperature and moderately free from salt. Two continuous indicating and recording mud-weight gages are now on the market which are fairly accurate if properly maintained.

Specific gravity of mud, of course, is dependent upon the percentage of solids and their specific gravity. It may be increased within moderate limits by merely adding more solids, but a point is soon reached at which further additions would make the mud too thick. More solids may be added without making the mud excessively thick, by using certain chemicals which tend to hold down the viscosity, but this is not commonly done. If still more weight is required, it is secured by adding some finely ground mineral of high specific gravity or by making a mud entirely of such material.

Mechanical Analysis

The coarseness of the material comprising the mud is important because it affects consistency and weight, and also because it has a marked effect upon the life of pump parts. An approximate idea of the percentage of coarse constituents can be obtained either by a settling test or a centrifuge test. For the former, Lytel[3] recommends diluting 100 c.c. of mud with 400 c.c. of water in a glass graduate. After a few minutes of settling a majority of the coarse constituents will go to the bottom and their volume in cubic centimeters is equal to the percentage in the original mud. Cartwright[4] recommends the centrifuge test, using the methods and equipment used to test oil. This was previously recommended and data presented by Collom.[5] Lytel finds that in many cases centrifuging is unsatisfactory, either because the line of demarcation

[3] H. M. Lytel, General Petroleum Corpn. of California.

[4] R. S. Cartwright: Rotary Drilling Problems, *Trans.* A. I. M. E., Petroleum Development and Technology (1928–29) 12.

[5] J. R. Suman: *Op. cit.*, 47.

between coarse and fine material is indefinite or because the position of this line varies widely with length of centrifuging and time of standing after centrifuging. In spite of objections, however, this test is good for field use because it can be made easily with equipment available for oil centrifuging and by methods familiar to the oil testers, and undoubtedly gives some information.

The size of the coarser constituents can be determined by a screen analysis. Such analyses are extremely illuminating and should be more generally used. The finest screen ordinarily available is 325 mesh (325 wires per inch), and the material that goes through this screen may or may not be fine enough to remain in suspension indefinitely, as the openings in such a screen are 0.0017 in. wide[6] and the maximum size of colloidal particles is about 0.0001 mm., or 0.000004 in.[7] Fineness must be further judged by precipitation tests, to determine the amount that the mud will subside or the amount of free water that will come to the top of the mud after a standard length of time (24 hr. is recommended as giving satisfactory indications, and dilution is not desirable). Note that settling tests may be used for two purposes; to determine percentage of "sand" or other coarse constituents, and to determine to what extent the remaining solids are of colloidal nature.

Consistency

Consistency is another important property of mud. This term will be used to include viscosity of fluid mud and plasticity and yield value of plastic muds. A mud that is too thin may wash the walls of the hole and cause caving; it may be lost to the formation in unlimited quantity; it may fail to carry cuttings out of the hole; and when circulation ceases it is apt to drop its load of cuttings and "freeze" the drill pipe. On the other hand, a mud that is too thick is hard to pump; it unloads its cuttings in the ditch imperfectly, if at all; it may build up the wall of the hole to such an extent as to make pulling and running of drill pipe difficult, and it results in slow drilling progress.

The distinction between a fluid and a plastic is important. Some muds are fluid and others are plastic. A fluid is commonly defined as a substance that will yield continuously to any force, no matter how small, if given sufficient time. A plastic will yield only a limited amount until the applied force exceeds some critical value. As applied to mud this means that if the mud is fluid cuttings will settle out if given sufficient time, but if the mud is plastic cuttings of less than a certain critical size (which may be very large) will never settle out. While the mud is in

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[6] U. S. Bureau of Standards screen. See A. F. Taggart: Handbook of Ore Dressing, 1184. New York and London, 1927. J. Wiley & Sons and Chapman & Hall.

[7] P. M. Travis: Mechanochemistry and the Colloid Mill, 10. New York, 1928. Chemical Catalogue Co.

the hole it should be in a plastic condition, so that whenever circulation ceases the cuttings (except perhaps the very coarse ones) will not settle out and stick the bit. On the contrary, when the mud is out of the hole it should behave as a fluid, so that it could be thoroughly freed of cuttings by merely being allowed to settle. The fundamental characteristics of fluids and plastics are illustrated best by Fig. 1, adapted from Bingham.[8]

Mud may change from a fluid to a plastic by geling. Many muds, especially those made from bentonite[9], if sufficiently concentrated, have

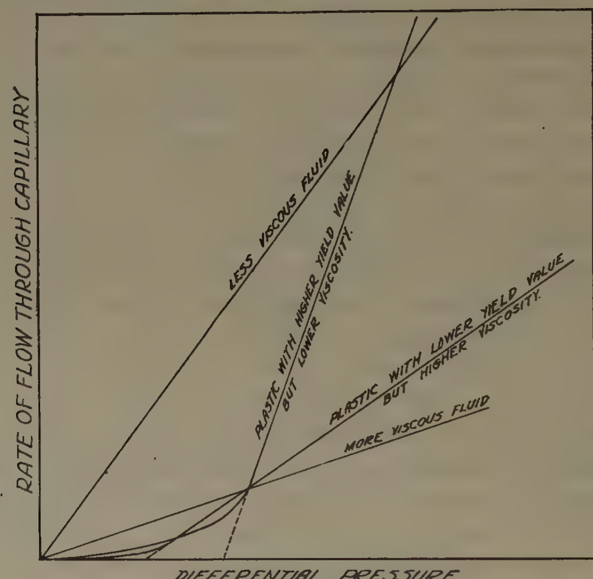

FIG. 1.—CHARACTERISTICS OF FLUIDS AND PLASTICS.

Viscosity is determined by slope of curve.

Yield value (of plastics) is determined by intercept on pressure axis of extension of straight portion of curves.

Note that dissimilar materials may have same apparent viscosity at certain rates of flow, indicated by intersection of curves.

the interesting and important property of being fluid while in motion but of setting into a fairly rigid gel upon standing. As Bingham puts it,[10] "The structure requires time to form and the fluidity at a given moment depends upon the recent history of the solution." This property is of considerable importance. Such a mud may be thin enough to be pumped easily and yet become plastic and prevent sticking of drill

[8] E. C. Bingham: Fluidity and Plasticity, Ed. 1, 217. New York, 1922. McGraw-Hill Book Co.

[9] For general information on bentonite, see C. W. Davis and H. C. Vacher: Bentonite, Its Properties, Mining, Preparation and Utilization. U. S. Bur. Mines *Tech. Paper* 438 (1928).

[10] E. C. Bingham: *Op. cit.*, 198.

pipe by settling of cuttings when circulation is stopped. It also tends to set as it enters the pores of the formation, and thus combats loss of fluid. Unfortunately, it exhibits the same tendency to gel while in the settling ditch and pit, and thus retains the cuttings tenaciously at the time when they should be unloaded. Special methods, mentioned later, perhaps may overcome this drawback.

For research purposes, viscosity and plasticity should be measured by some standard form of viscosimeter that gives accurate readings in absolute units. Such an instrument is described and illustrated by Bingham.[11] For rough measurements in the field, the funnel viscosimeter shown in Fig. 2 has been found very satisfactory. Its readings, however, are only comparative, and are a measure of kinematic viscosities which must be divided by specific gravity to make them comparable with absolute viscosities. Over a moderate range of specific gravity, the distinction is not very important, but heavily weighted muds have kinematic viscosities that are misleadingly low. In the following paragraphs, unless otherwise stated, the term viscosity will be used to mean apparent viscosity as measured with the funnel viscosimeter. In the case of plastics, this is really a combination measure of yield value and plasticity that gives only a practical indication of the fluidity.

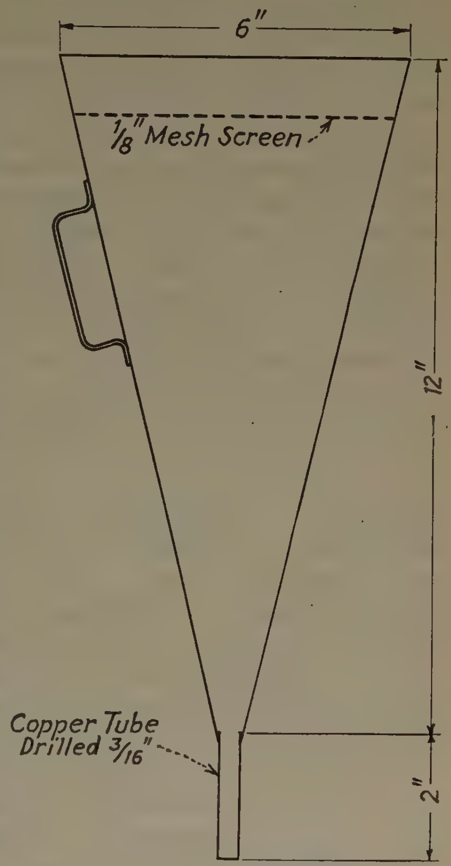

FIG. 2.—FUNNEL VISCOSIMETER.

Measurement of viscosity made by pouring 500 c.c. of fluid into funnel and measuring time of efflux with stop watch.

Hold finger over orifice while pouring in mud and until starting stop watch.

Check with water occasionally. Time of efflux for clear water should be 18.5 seconds.

Characteristics Desired

There is considerable difference of opinion as to the character of mud desired for various drilling conditions, chiefly concerning consistency.

[11] E. C. Bingham: Investigation of the Laws of Plastic Flow. U. S. Bur. Stds. *Sci. Paper* 278 (1916) 311.

It is generally agreed that a mud should be heavy enough to withstand any gas pressure that is likely to be encountered, but increasing weight by ordinary means increases viscosity, which may be objectionable, and often necessitates a cash outlay for material. The practical compromise is hard to establish. It is believed that in many cases, heavier muds are used than are needed, and that most blow-outs are caused either by loss of circulation (or otherwise lowered fluid level) or by gas-cut mud. Both of these conditions may be caused or at least made worse by using too heavy a mud; loss of circulation is the result of excess pressure in the hole and can sometimes be stopped by lightening the mud (preferably not thinning it), and gas-cutting is caused by the mud being so viscous or plastic (which ordinarily accompanies high weight) that bubbles of gas from the formation cannot escape. There are times, however, when the heaviest mud that can be secured is none too heavy.

Proper consistency is much more a matter of opinion than is weight. This is partly due to failure to distinguish between consistency and weight. An apparent viscosity of 22½ to 25 sec. by the funnel viscosimeter (Fig. 2) has been found great enough for ordinary purposes, and at the same time low enough to permit cuttings to settle out satisfactorily in the ditch. Where a hole tends to cave or circulation to be lost, thicker mud may be necessary.

It is, of course, desirable to keep the percentage of coarse constituents as low as possible, as such material causes rapid wear of pumps, probably is useless for plastering the walls of the hole and is a potential cause of stuck drill pipe. Just how coarse a material can be tolerated is questionable. Some people contend that any particle too large to be in the colloidal state is at least "inert" and useless, if not positively objectionable. This would condemn all particles larger than 0.000004 in. dia. (approximately 125,000 mesh).[12] At the other extreme, use of a vibrating screen (discussed later) with 30-mesh screen is maintaining mud in an apparently satisfactory condition.

Treatment of Mud

Treatment of mud at the well to secure and maintain the properties considered desirable is generally very simple, it consists of adding water to reduce weight or viscosity, or adding dry or thick wet mud material to increase weight and viscosity (no separate control of these properties), and circulating the mud through a ditch or pit, or both, with the hope that the cuttings will settle out. If the material used is good and is suited to the drilling conditions, and is properly diluted, the weight and viscosity will be right, and if dilution or thickening is correct, the values

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[12] Herschel in J. Alexander's Colloid Chemistry, 1, 733. 1926–28. New York. Chemical Catalogue Co.

of these properties will be satisfactory. Under favorable conditions the ditch may be fairly effective in removing the cuttings. More often, however, cuttings accumulate and the mud becomes progressively worse until it has to be dumped and replaced with new mud (at considerable expense) or until failure to do so causes a bad fishing job.

Admixtures

Better methods for treating mud and controlling its properties are coming into use. One of the best known is the use of special materials

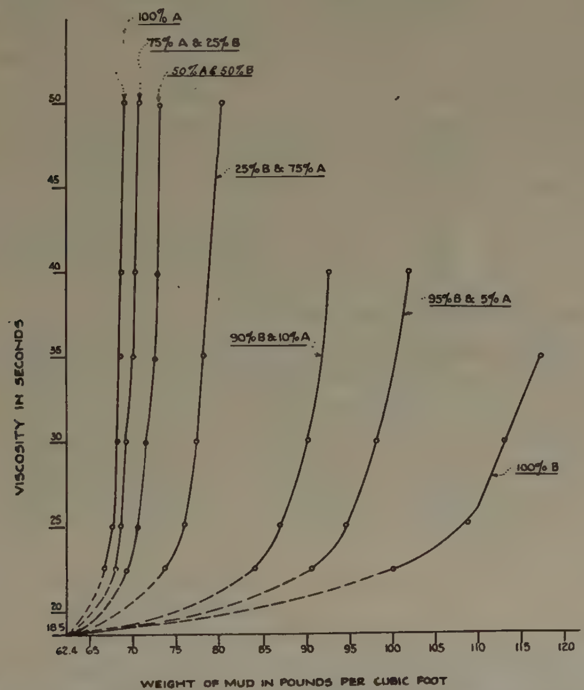

Fig. 3.—Showing how muds having any reasonable combination of weight and viscosity can be made from mixtures of two materials.

that give special properties. With such special materials, muds having practically any combination of qualities can be made. For example, Fig. 3 presents curves showing that mud having any reasonable combination of viscosity and weight can be made from the proper mixture of two well-known prepared materials. Similar results, covering a narrower range, can be secured from combinations of various native muds.

Chemical Reagents

The consistency of a mud can be greatly altered without materially changing the weight or concentration by the use of various chemical

reagents. Such treatments, however, should be tried out on a sample of the mud on which it is proposed to use them, as some treatments that work well on one mud may have an opposite or other undesirable effect on another mud. For example, addition of a small amount of sodium silicate to an inert mud will decrease its viscosity greatly, probably acting as an emulsifying agent, while a mud fluid having an acid reaction will be thickened by the same treatment, probably through the formation of silica gel.[13] Similarly, a stiff mass of clay will be made fluid by the addition of a little sodium hydroxide or carbonate, and incidentally can be resolidified by the addition of a little acid.[14] According to Fisher,[15] a mixture of sodium aluminate and sodium hydroxide will enormously increase the mud viscosity of a swelling clay such as bentonite but will have practically no effect on a nonswelling clay. The apparent conflict probably is due to different kinds of mud, one being a positive and the other a negative colloid. The use of hydraulic lime coagulates a mud, the colloidal particles combining into larger particles, which may cause them to clog crevices and thus restore lost circulation.[16] Mud so treated is not suited for further use. Most clays are flocculated by acids and by acid or neutral salts. Small amounts of alkalies and of alkaline salts deflocculate them, but larger amounts cause flocculation.[14]

Colloids may be classified as suspension colloids and emulsoid colloids. The former have a relatively low viscosity, or for a given viscosity they have a relatively high specific gravity. They are precipitated readily by any electrolyte—acid, alkali, or salt. The suspensoid colloids, of which bentonite is an example, are not so easily precipitated by electrolytes, and have high viscosity or low weight for a given viscosity.[17]

Water for Mud Fluid

The nature of the water used in mixing and thinning has a remarkable bearing on the properties of mud. Waters good enough for domestic use may contain enough dissolved impurities to produce surprising effects. This is illustrated by Fig. 4, which shows graphically the results of precipitation tests of four different mud materials with water from 10 sources. Two of the materials (*B* and *C*) precipitated badly in all waters, while material *A* settled badly in water No. 7 but not at all in others. Material *D*, which is much like *A* in many other respects, precipitated badly in several waters that did not precipitate *A*, and

[13] J. H. Clark: Personal communication.

[14] J. Alexander: Colloid Chemistry, Ed. 3, 108. New York, 1926–28. Chemical Catalogue Co.

[15] G. Fisher, General Petroleum Corpn. of California.

[16] J. R. Suman: *Op. cit.*, 48.

[17] P. M. Travis: *Op. cit.*, 108.

stayed up perfectly in the water that did precipitate A. Therefore waters cannot be classified as good or bad except with respect to certain materials.

"The precipitation of fine particles by electrolytes is well illustrated on a large scale in nature, the finely divided clay carried by many rivers being caused to deposit when the river water mingles with the sea. In this way the silting up of river mouths and the formation of deltas, as in the case of the Nile and of the Mississippi, are brought about."[18]

Various writers point out the significance of the "pH value" of a water or mud as an indication of the behavior to be expected and the proper treatment. This is merely a measure of acidity. Dice[19] suggests

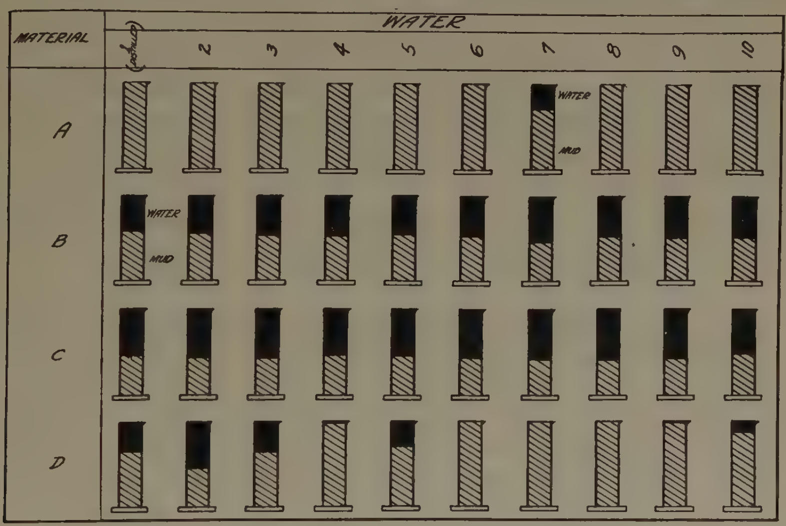

FIG. 4.—PRECIPITATION TESTS OF ROTARY MUDS.
22.5 second mud cut back with equal volume water. 48 hr. settling.

that since any electrolyte tends to precipitate a colloid, a measure of the electrical conductivity of a mud should be significant. This would probably be most applicable in the case of suspensoids.

Aside from the more obvious objections to a mud that settles, flocculation (a common form of settling or precipitation) apparently is objectionable because it hinders separation of cuttings. Flocculent mud apparently has sufficient structure to retain cuttings that would settle out if the mud were of the same weight but dispersed. This is evidenced by Table 1, a data sheet showing conditions of mud at an actual well before and after using a water treatment that reduced flocculation. Note that the average "sand" content, while still objectionably high after the

[18] Encyclopedia Brittanica, Ed. 13. 1926.
[19] M. E. Dice, General Petroleum Corpn. of California.

treatment (due to other unfavorable conditions), was less than half of what it had been before.

The viscosity of a mud is said to be largely dependent upon the number of colloidal particles per unit volume and almost independent of the size of the particles (so long as they are colloidal). For two muds made to the same viscosity, the one having the larger particles should therefore have the higher specific gravity. Table 2, giving the percentage of solids and specific gravities of muds all made to the same viscosity from four materials, in ten different waters, shows that for the same viscosity different amounts of material are needed in different waters and different gravities result.

Ditches and Pits

Design of ditches and pits will bear a great deal of study. If the mud is a true fluid, the problem is relatively simple. From the literature on ore dressing, the settling rates of particles of various sizes and gravities can be learned, and having decided the maximum size of particle that can be tolerated, the necessary size of ditch can be calculated. Taggart[20]

TABLE 1.—*Effect of Using Treated Water-mud Data*

Well——————— Location———————

Date	Well			Mud				Remarks
	Depth, Ft.	Casing	Status	Weight, Lb. per Cu. Ft.	Viscosity, Seconds	Sand (Settling), Per Cent.	Loss Bbl. per Hr.	
5-12-30	1707	18″ at 240′	Coring	78	31	17		
5-13-30	1712	18″ at 240′	Coring	75	34	18	None	Using untreated water.
5-14-30	1732	18″ at 240′	Coring	74	30	25	None	
5-15-30	1759	18″ at 240′	Coring	75	37	30	None	
5-17-30	1811	18″ at 240′	Coring	76	35	25	None	
5-20-30	1930	18″ at 240′	Reaming	76	43	23	None	
5-23-30	1967	18″ at 240′	Coring	75	28	26	None	
Average before using treated water.					34	23.4		
5-27-30	2066	18″ at 240′	Coring	76	23	6	None	Mud fluid washed to reduce sand content.
5-28-30	2112	18″ at 240′	Coring	75	30	7	None	Using treated water.
5-29-30	2151	18″ at 240′	Coring	77	41	15	None	
5-30-30	2151	18″ at 240′	Reaming	77.5	43	12	None	
5-31-30	2198	18″ at 240′	Coring	76.5	37	12	None	
6- 1-30	2199	18″ at 240′	Reaming	77.5	41	10	None	
6- 5-30	2271	18″ at 240′	Coring	77	41	12	None	
6- 6-30	2301	18″ at 240′	Coring	75.5	35	8	None	
6- 8-30	2366	18″ at 240′	Reaming	77	42	12	None	
6- 9-30	2377	18″ at 240′	Coring	76.5	37	9	None	
Average since using treated water.					38.6	10.6		

[20] A. F. Taggart: Handbook of Ore Dressing. New York and London, 1927. J. Wiley & Sons and Chapman & Hall.

TABLE 2.—*Effect of Kind of Water upon Specific Gravity*
All Muds Made to Viscosity of 22½ Seconds, Funnel Viscosimeter

Water	Material A		Material B		Material C		Material D	
	Solids, Per Cent.	Spec. Grav.	Solids, Per Cent.	Spec. Grav.	Solids, Per Cent.	Spec. Grav.	Solids, Per Cent.	Spec. Grav.
1	13.1	1.07	41.6	1.32	37.4	1.32	4.3	1.02
2	12.6	1.08	37.6	1.31	39.5	1.33	6.0	1.03
3	13.0	1.08	35.5	1.30	38.2	1.31	4.8	1.03
4	12.4	1.08	40.7	1.32	39.6	1.32	4.3	1.01
5	12.5	1.07	36.4	1.30	37.4	1.39	6.2	1.01
6	13.1	1.06	37.6	1.33	40.2	1.33	4.6	1.02
7	18.8	1.13	42.4	1.33	45.0	1.37	7.5	1.05
8	17.2	1.10	38.4	1.33	36.8	1.29	3.9	1.03
9	15.9	1.09	35.5	1.32	36.0	1.30	4.8	1.03
10	10.6	1.08	37.4	1.32	34.3	1.29	6.1	1.04

and Richards[21] both give the necessary data and equations. Taggart points out (p. 583) that the effectiveness of a settling ditch is independent of its depth and also of its ratio of length to breadth. It horizontal area or product of length by breadth determines its effectiveness.

Finkey[22] advocates the rising current classifier as opposed to the horizontal current classifier. For liquid muds the suction pit or an auxiliary might be made an effective rising current classifier by adding a conductor pipe to take the flow from the ditch nearly to the bottom of the pit, and taking suction from a substantially higher level. Of course, provision must be made and used for removing settlings from the pit if it is to be effective. Suction pipes are now sometimes arranged so that they can be raised or lowered, but all too often they are let down nearly to the bottom of the pit and left there. As a result no rising current classification is possible, and what sand is separated by horizontal flow is picked up eventually by the suction.

Unfortunately for the success of ditch and pit classification, many muds (probably the best muds) gel or otherwise become plastic when velocity of flow becomes small. Thus reduction of velocity, which otherwise would permit settling, prevents it. With such materials it is found that there is a certain intermediate velocity of flow at which settling is most nearly satisfactory. This has been noted by Benjamin[23] in other industries. With some muds this is evidenced in connection with rotary

[21] R. H. Richards: Ore Dressing. New York, 1903–09. McGraw-Hill Book Co.

[22] J. Finkey: Scientific Fundamentals of Gravity Concentration. Trans. by C. O. Anderson and M. H. Griffitts, 113. Rolla, Mo., 1930. Mo. School of Mines *Bull.* Tech. Series **11**, No. 1.

[23] G. L. Benjamin, The Dorr Co., Los Angeles.

drilling by the sand settling in the high-speed conveyor ditch instead of in the deep "settling" ditch.

Fortunately the change from liquid to plastic state requires an appreciable length of time. This suggests that numerous quick changes from turbulent flow to very slow flow will produce satisfactory classification even of geling muds. It has been observed that with plastic muds most of the cuttings that settle do so in the first few feet of the big ditch, or immediately after turning a corner. It appears useless to have ditches of any considerable length without riffles, changes of direction or other means of temporarily creating turbulence to break down the structure of the plastic. Ditches of considerable width but slight depth, equipped with frequent dams, baffles or riffles are tentatively recommended. Table 3 shows analyses of mud samples taken from the head and foot of an ordinary ditch while drilling. Note that all constituents down to 200 mesh are reduced.

Dilution, Classifying and Rethickening

Probably any mud can be freed of its coarser constituents by well-known means of classification if it is diluted sufficiently. Dilution, however, necessitates thickening of the mud before it is again suitable for use. Thickening is generally accomplished by flocculation, which will take place only if the mud is naturally noncolloidal or is flocculated by chemical treatment. As colloidal mud is generally considered desirable, this is an objection to the process. The flocculated mud generally may be deflocculated (returned to its colloidal state) by further chemical treatment, but this may not always be practical. Such systems appear most applicable for large installations serving a number of wells.

A paper describing a large plant of this type, presenting operating data, is being prepared by Wickstrum.[24]

TABLE 3.—*Effectiveness of Ordinary Ditch*

	Sample	
	From Flow Line	From Foot of Ditch
Total solids, by weight, per cent	22.6	22.5
Screen analysis of solids, per cent.		
On 70 mesh	0.40	0.18
On 100 mesh	0.31	0.13
On 200 mesh	2.74	2.44
On 325 mesh	1.46	1.51
Through 325 mesh	95.09	95.74

[24] H. W. Wickstrum, Associated Oil Co., Los Angeles.

Centrifuging

A centrifuge which is being tried is proving remarkably effective. Its nominal capacity is 100 to 300 gal. per minute but it has operated successfully at rates up to 560 gal. per minute. Table 4 gives average data for two sets of samples of mud to and from this machine and shows that it removes practically all of the material of +100 mesh or coarser, most of the +200 mesh and some of the +325 mesh. The only apparent objection to the centrifuge from the standpoint of results is that it rejects a considerable amount of 325-mesh material, which may be considered valuable. This effect combined with the large capacity of the machine suggests that its proper application is for the occasional reclamation or cleaning of mud rather than for continuous use.

TABLE 4.—*Effectiveness of Centrifuge*

	Sample		
	Before Centrifuging	After Centrifuging	Tailings
Specific gravity	1.35	1.24	1.67
Viscosity, sec. (funnel)	29.2	27.0	50+
Total solids, by weight per cent	48.1	36.6	65.3
Screen analysis of solids, per cent.			
On 30 mesh	1.12	0.00	1.345
On 70 mesh	11.22	0.095	14.89
On 100 mesh	5.245	0.105	7.555
On 200 mesh	15.60	2.735	18.425
On 325 mesh	8.89	6.80	8.015
Through 325 mesh	57.925	90.265	49.77

Doerner[25] points out that there is no fundamental difference between gravity concentration and centrifugal concentration, except that in the latter the acting force is many times greater and the process therefore many times faster. This is probably true in slimes dealt with in the mining industry, which are fluids, but in the case of geling muds such as are sometimes used for drilling there may be important differences. It appears that in a centrifuge there may be enough force to separate even very fine particles from a plastic mud. It may also be that sufficient turbulence exists in a centrifuge to prevent geling while at the same time sufficient force is exerted on the particles to cause their separation in spite of the turbulence.

[25] H. A. Doerner: Centrifugal Concentration, Its Theory, Mechanical Development and Experimental Results. U. S. Bur. Mines *Tech. Paper* 457 (1929).

Screening

Vibrating screens are being tried by several companies, and seem to have considerable merit. In some cases it is planned to have the screen in operation whenever the mud is being circulated, and in others the intention is to use it only occasionally to clean the mud, by-passing it the rest of the time for the sake of economy.

Screens remove practically all particles of diameter greater than the width of the openings through them. Screens finer than 60 mesh have rarely if ever been used. Screens of 30 or 40 mesh appear much more practical, and it would seem that material much finer than any of these meshes would be objectionable. As noted previously, material coarser than 125,000 mesh is not colloidal. Experience, however, indicates that at least under some conditions continuous use of a 30-mesh vibrating screen will keep mud in good condition for an unlimited length of time.

Table 5 gives analyses of mud samples from a well where a 30-mesh vibrating screen was in use. Comparing analyses of mud before and after passing through the screen, it appears that the screen eliminated practically all of the +30-mesh material and also a substantial fraction of the +70 and +100-mesh. The screen analysis of the material passing over the screen confirms this in the case of the +70-mesh, but only slightly in the case of the +100. Viscosity and weight were not affected appreciably, and "sediment" by the settling test was reduced from 15 to 10 per cent.

TABLE 5.—*Effectiveness of Vibrating Screen*

	Sample		
	Before Screening	After Screening	Over Screen
Total solids, by weight, per cent	32.9	32.7	69.1
Screen analysis of solids, per cent.			
On 30 mesh	0.15	Trace	32.60
On 70 mesh	2.20	1.95	34.80
On 100 mesh	2.45	2.10	1.10
On 200 mesh	5.90	6.30	2.75
On 325 mesh	3.70	3.15	0.50
Through 325 mesh	85.60	86.50	28.25
Weight, lb. per cu. ft.	73	73	
Viscosity, sec.	25	25	
Sediment, settling test, per cent	15	10	

More interesting, perhaps, than the data given above is the fact that during 11 weeks use of this screen the mud has never been completely replaced, and no appreciable volume of cuttings has accumulated in the

ditch. In spite of this, the mud is still in excellent condition, so far as can be determined by observation and by simple field tests. It must be explained, however, that some of the drilling has been through fairly good mud-making material, which has been gradually replacing the original mud, and a limited amount of new material has been added from time to time.

While screens considerably finer than 30 mesh have been proved possible for some conditions, they are apt to be unsatisfactory, because they become clogged and because their maintenance cost is higher. Thick sticky mud goes through the finer screens with difficulty. A small amount of oil may also clog them. Finkey[26] says that "the costs of maintenance of a screen are greater the smaller the width of the opening" and that screens are generally used in Europe only for material of grain size larger than 1 mm. (approximately 12 mesh). Oil-field experience has already confirmed the idea that the finer screens are much less durable, but a screen life of 374 hr. for 30-mesh monel screen cloth has been attained, and the hourly cost based on such a life is not large compared with the benefit that is being derived. Still better screen life is may be secured.

In judging the effectiveness of any sand-separating process for individual wells, it is desirable actually to measure the volume rate of removal of the coarse material and compare this rate with the volume rate of making hole. With vibrating screens this is easy, as the "tailings" from the screen can be easily caught and measured for a definite length of time. The rate of flow of tailings from screens is impressively large to look at or measure but surprisingly low when expressed in percentage of the mud stream, and just about accounts for the rate at which hole is being made. The rate of separation of cuttings in one case was just 1 qt. per minute, which was less than 0.1 per cent. of the total volume of mud being circulated but accounted for 40 ft. of 12-in. hole per 24 hr. The amount of mud shoveled from ditches rarely begins to account for the volume of hole made.

Conclusions

While there are many points in the selection and use of drilling mud that are open to controversy, there are also many about which there is little doubt. The application of facts and principles that are known is resulting in a rapid improvement in general practice and there is little doubt that further intensive investigation will result in still further improvements in practice. Such improvements should greatly reduce cases of blow-outs and stuck pipe, greatly increase life of pump parts and reduce expenditures for purchase, hauling and disposal of mud.

[26] J. Finkey: *Op. cit.*, 98.

DISCUSSION

(V. H. Wilhelm presiding)

(The following refers also to the paper by C. P. Parsons, which begins on page 227.)

E. J. Maust,* New York, N. Y.—This paper brings out some very interesting points, especially regarding the degree of dispersion. There has been little attention paid to this, as most muds are flocculated; that is, the colloids are grouped together, which makes them act as consolidated particles rather than individual colloids.

It appears that the control of this characteristic of mud is probably most important. The dropping out of the cuttings is controlled by the degree of flocculation and the yield point apparently determines the ease with which they start to drop. The viscosity of the mud tends to stop the settling of cuttings. This apparently is borne out in the fact that sand finer than 20 mesh seldom drops out in the ditches. It is very difficult to understand how a twist-off could be due to the sand dropping out of the mud.

Muds that are fairly well flocculated filter on the sand formation and produce a thick cake. In fact, the cake could completely fill the hole except for a small portion around the drill stem. It appears possible that where a very thick cake is formed against the sand wall, the mud stream will force through and will produce a channel in one side of the hole. It is probable that a high velocity at this one point will cut into the formation and probably keep a certain amount of the wall sand in what is known as a "teeter" condition. As soon as circulation is stopped, this sand drops as a body.

It has been observed in the laboratory that a quantity of sand placed in mud *en masse* will drop through the mud instantly but if this sand is stirred up in the mud, it will remain in permanent suspension. It appears therefore that the degree of flocculation of the mud is perhaps responsible for the stuck drill pipe due to sand dropping out from the side wall, but not due to cuttings themselves dropping out of the mud.

The interesting thing in this connection is that new muds or clays ordinarily mined and mixed wet and sent to the well are seldom in good condition to be used. Colloids are difficult to wet, because they group together. In that condition they filter rapidly. They act as sand particles themselves and it is only after a long period of time and contact that these groups of colloids are entirely broken up.

In studying reclaimed mud at Ventura, we find that the mud after being used, some of it for several years, is in better shape for use in the well than new mud freshly mined. Reclaimed mud, of course, has had the cuttings removed. The cutting removal puts the mud back into its former shape from the standpoint of fineness. We find the reclaimed mud is actually finer and has a larger colloidal content than the mud newly mined.

There is one exception I would like to make to Mr. Marsh's paper, in regard to the thickening of mud after it is classified. He mentioned that thickening can be accomplished only with mud that is noncolloidal. All muds contain colloids. In fact, if mud had no colloids it would be unsuitable for use. Some muds require larger areas and a longer period of contact; that is, longer time to stand in order to obtain density after treatment.

The terms colloidal and noncolloidal are hard to define. All muds have varying percentages of colloids. A colloid is assumed to be $\frac{1}{100}$ micron. Most muds apparently have 50 per cent. of material finer than 3 microns, which would indicate it to have from 20 to 30 per cent. colloids.

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* Industrial Development Engineer, The Dorr Co.

Material around 3 microns acts very much like colloids. One of the few truly colloidal materials is bentonite, which is very difficult to wet. The wetting of bentonite is a matter of contact with water under pressure. In a mixture of bentonite and water left standing for a period of time, a viscosity may be obtained that would be pumpable. But when forced through sand under pressure, it will come out with the same percentage of solids and be so thick that it cannot be pumped.

R. A. Kinzie,* San Francisco, Calif.—Did much mud go deeply into the sand in the formation of the cake on the side of the hole you mentioned?

E. J. Maust.—Perhaps ½ in. at most.

J. B. Stevens,† Fellows, Calif.—What is the effect of temperature on the characteristics of mud?

E. J. Maust.—The viscosity of most muds is decreased on heating, but the interesting thing is that the degree of flocculation is also increased upon heating. There will be a greater tendency to seal off formations at high temperatures than at low temperatures.

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* Santa Cruz Portland Cement Co.
† Associated Oil Co.

Chapter III. Engineering Research

Preliminary Report on an Investigation of the Bureau of Mines Regarding the Solubility of Natural Gas in Crude Oil*

By Ben E. Lindsly,† Bartlesville, Okla.

(New York Meeting, February, 1931)

Petroleum engineers generally are familiar with the investigations of Dow and Reistle,[1] Beecher and Parkhurst,[2] and Dow and Calkin[3] relative to the solubility of natural gas in crude oil. Since the publication of the results of those investigations and the work of Mills and Heithecker,[4] little additional knowledge on this interesting and important subject has appeared in the petroleum engineering literature.

The reports of Beecher and Parkhurst and Dow and Calkin agree substantially. The data from both investigations showed that, under the conditions of the tests, the solubility of natural gas in crude oil increased in direct proportion to the pressure at which the gas was put into solution, and the solubility decreased to a considerable extent with increased temperature. These facts, and others relating to the changes in viscosity, surface tension and specific gravity of the crude caused by the solution of gas in the oil, have been given due consideration in the petroleum industry, and the recognition of these facts has resulted in a great improvement in the technique of producing oil.

However, in these first experiments, various grades and types of weathered crude oil were contacted at various pressures up to 500 lb. per sq. in. gage with gases deficient to a considerable degree in the heavier hydrocarbons, as compared with the gas that was originally in solution in the oil in its natural underground reservoir. The amount of dissolved gas that was liberated upon reducing the pressure to 1 atm. was measured. For these reasons, the complete significance of the effect of dissolved gases in crude oil, as it occurs in nature, cannot be determined directly from the data obtained under the conditions of the tests as described.

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* Published by permission of the Director of the U. S. Bureau of Mines.

† Senior Petroleum Engineer, U. S. Bureau of Mines.

[1] D. B. Dow and C. E. Reistle, Jr.: Absorption of Natural Gas and Air in Crude Petroleum. *Min. & Met.* (1924) **5**, 336–337.

[2] C. E. Beecher and I. P. Parkhurst: Effect of Dissolved Gas Upon the Viscosity and Surface Tension of Crude Oil. Petr. Dev. and Tech. in 1926, A. I. M. E. (1927) 51.

[3] D. B. Dow and L. P. Calkin: Solubility and Effects of Natural Gas and Air in Crude Oils. U. S. Bur. Mines *Rept. of Investigations* 2732 (1926).

[4] R. Van A. Mills and R. E. Heithecker: Volumetric and A.P.I. Gravity Changes Due to the Solution of Gas in Crude Oils. U. S. Bur. Mines *Rept. of Investigations* 2893 (1928).

In the present investigation, well-head samples were obtained in suitable bombs at the existing well-head pressure from flowing wells, and the amount of gas that was liberated upon gradual reduction of pressure was measured and analyzed. Samples under a pressure as high as 1686 lb. per sq. in. abs. were obtained.

The difference in data obtained under the two general sets of conditions can be shown best by the following comparison: Beecher and Parkhurst found that weathered Bradford crude of 44.3° A.P.I. gravity dissolved 70 cu. ft. of dry natural gas per barrel of oil when the two substances were contacted under pressure up to 300 lb. per sq. in. gage. The author, working with Kettlemen Hills crude of 44.5° A.P.I. gravity, found that a well-head sample liberated 275 cu. ft. of dissolved gas when the pressure was reduced through a corresponding pressure range. The difference of 205 cu. ft. between the results of the two studies cannot be attributed to the fact that one crude was from California and the other from Pennsylvania, but rather to the different methods, as explained, which were employed in making the determinations.

In the application of experimental data obtained from weathered oil and dry natural gas, there is no doubt that the results of calculations reflecting the changes in the physical properties of natural oil-gas mixtures have been correct in trend, but it now appears that the numerical values of these calculations may have fallen short in magnitude. The fact that live oil obtained at the well-head contained greater quantities of dissolved gas than oil that had been in storage for some time was indicated to the author by his experiments on Burbank crude,[5] which showed that 78 cu. ft. of gas per barrel of oil was liberated from solution in the oil when the pressure was reduced from 2 lb. per sq. in. gage to 26 in. vacuum; a reduction in absolute pressure of about 15 lb., giving a final pressure of about one-tenth the original pressure. On the other hand, Dow and Calkin[6] found that it required 378 lb. per sq. in., or about 27 times the original pressure (which was atmospheric) to dissolve the same quantity of dry natural gas per barrel of weathered Oklahoma crude, which had a gravity of 31° A.P.I.

These great differences in the volume of gas that is in solution naturally in crude oil, as compared with the volume of gas that will dissolve in weathered oil when it is contacted with dry natural gas at high pressures artificially, indicate that many fundamental data regarding the solubility of gas in oil in the natural state are yet to be obtained.

This preliminary paper gives the major findings of a study of the Bureau of Mines which is being made to obtain data on the physical and chemical characteristics of natural oil-gas mixtures. By proper inter-

[5] B. E. Lindsly: Use and Limitations of Vacuum in the Recovery of Oil. Petr. Dev. and Tech. in 1926, A. I. M. E. (1927) 166.

[6] D. B. Dow and L. P. Calkin: *Op. cit.*

pretation, it is believed that these data will indicate true solubility conditions in natural reservoirs.

Apparatus and Procedure

Fig. 1*A* shows two high-pressure bombs connected by a ½-in. lubricated stopcock (1). These bombs are forged from 3-in. double extra heavy seamless tubing. Their outside and inside diameters are approximately 3½ and 2¼ in., respectively. The wall thickness, therefore, is approximately ⅝ in. The length of each bomb is about 15 in. and the capacity of the lower bomb *a* including the port of stopcock 1 is approximately 705 cu. cm. All parts of the apparatus were tested to 2500 lb. per sq. in. hydraulic pressure. Valve 2 connected at the side of bomb *a* is the inlet valve and valve 3 at the top of the upper bomb *b* is the outlet. These are forged-steel needle valves. Valve 2 is connected to a coil of ¼-in. copper tubing *c* that leads to the connection at the well head. The assembled bombs and copper tubing are placed in a 70° F. water bath, and the apparatus is then subjected to the well pressure by opening valve 2. After examining the apparatus carefully for leaks, valve 3 is opened slightly, and, with lubricated stopcock 1 connecting the two bombs open, the oil and gas flow through the copper coil and the bombs at well-head pressure under flowing conditions. The oil drops to the bottom of bomb *a* and the gas discharges from the top of the upper bomb *b*. This operation is continued until oil discharges with the gas from needle valve 3. After the oil has discharged from the top needle valve 3 for about 10 min., this valve and also the inlet or lower needle valve 2 are closed, the copper tube is disconnected and the assembled bombs are allowed to remain in the 70° F. bath for 15 or 20 min., thereby allowing any gas bubbles that may be adhering to the walls of the bottom bomb to pass upward through stopcock 1 and rise to the top of the upper bomb. During this stabilizing process, the lower bomb is vigorously hammered at frequent intervals in order to jar loose any gas bubbles which may have adhered to the sides of the lower bomb.

Pressure gage *d* indicates the pressure at which the sample is taken. Pressure gage *e* is for the purpose of indicating leaks that may be present after the sample is obtained. Thus during the sampling operation, valve 4 is closed and remains closed until the sampling is complete. At that time, valve 1 is closed and valve 4 is opened. Leaks in the apparatus become apparent by a more or less continuous pressure drop, as indicated by gage *e*. Gage *e* was highly important in the experiments at the Oklahoma City field, where a number of samples were taken at one time, packed in ice and transported to Bartlesville, Okla., a distance of 200 miles, where they were placed in cold storage for periods varying from a few days to two or three weeks before the gas was drawn off into

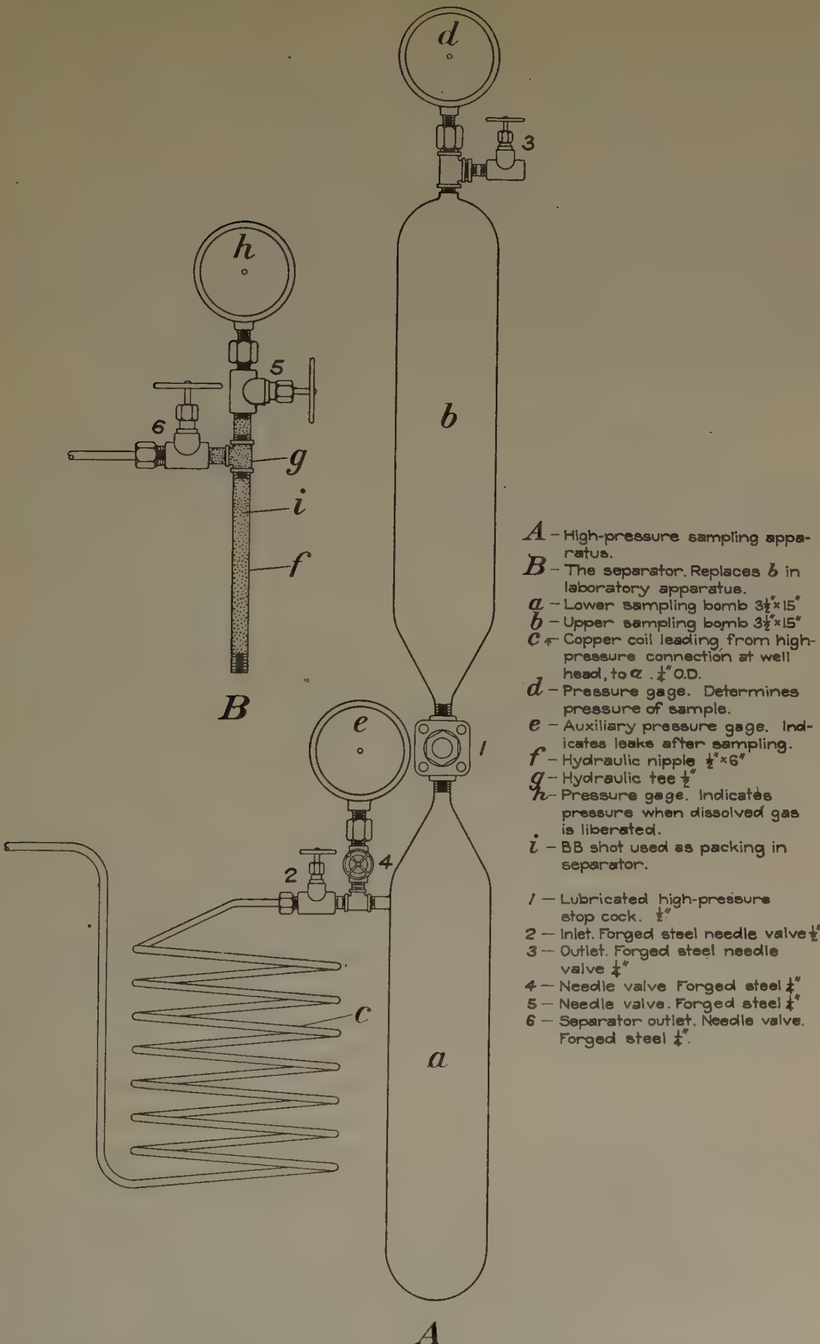

FIG. 1.—HIGH-PRESSURE SAMPLING APPARATUS. SEPARATOR *B* REPLACES *b* IN LABORATORY OPERATIONS.

measuring bottles. In the California work, however, only one sample was taken at a time, and as bombs *a* and *b* were allowed to remain assembled during the short period of transportation from well to laboratory, any pressure drop that might occur could be readily observed on gage *d*. Consequently, under these conditions, there was no advantage in using gage *e*.

In preparing the apparatus and the gas-saturated sample for the subsequent laboratory work, the pressure is released from bomb *b*, and its contents are discarded. The purpose of the upper bomb is to provide a means of completely filling the lower bomb with gas-saturated oil, without any free gas. At this stage of the operation, bomb *a* is ready to be prepared for drawing off the gas from the gas-saturated oil.

Field Laboratory Apparatus and Procedure

The upper bomb *b* is replaced by an assembly (Fig. 1*B*) called the "separator." This assembly consists of a hydraulic nipple *f*, ½ by 6 in., a ½-in. hydraulic tee *g*, and needle valves 5 and 6, which are screwed into the top and the side outlets respectively of the tee. Pressure gage *h* of suitable range is screwed into needle valve 5, and the needle valve 6 on the side outlet of the tee serves as the outlet for the gas coming out of solution as the pressure is released from bomb *a*. The tee *g* and the nipple *f* are full of BB shot to reduce the space and to knock down any oil that may have a tendency to "foam up" into the separator from the lower bomb. While unscrewing the top bomb and replacing it with the separator, the temperature of bomb *a* is kept below 70° F. by means of an ice pack. After assembling, the separator and bomb are placed in a 70° F. bath, and the air in the separator assembly and in gage *h* is exhausted by means of a vacuum pump; this evacuation was accounted for in subsequent measurements and calculations. Valve 6 is then closed, and stopcock 1, connecting the separator and bomb *a*, is opened gradually; allowing the pressure to build up in the separator as slowly as possible. In the experiment represented by curve 1, Fig. 2, the pressure in the bomb was reduced from 1672 to 1396 lb. per sq. in. abs. during the first operation of releasing gas from bomb *a* to the separator. It took about 15 or 20 min. for this pressure to become stabilized at the lower pressure. Throughout the period the bomb was hammered repeatedly. After the pressure became constant, gage *h* was read, stopcock 1 was closed and the gas in the separator was drawn off slowly through rubber tubing connecting outlet needle valve 6 to calibrated 1-gal. bottles which had previously been filled with water. The gas in the calibrated measuring bottles and in the separator and tubing was brought to atmospheric pressure by means of a leveling bottle, and the volume of the gas liberated for each pressure drop was determined. At each gas-volume reading,

the barometric pressure and the atmospheric temperature were recorded. It was assumed that the temperature of the gas in the bottles was the same as that of the atmosphere. The procedure of releasing gas from solution in the oil by stabilizing the pressure within the separator and bomb *a* and then collecting and measuring the gas contained in the separator, by manipulating valves 1 and 6, was repeated until the pressure in the bomb was reduced to atmospheric pressure. Upon opening the

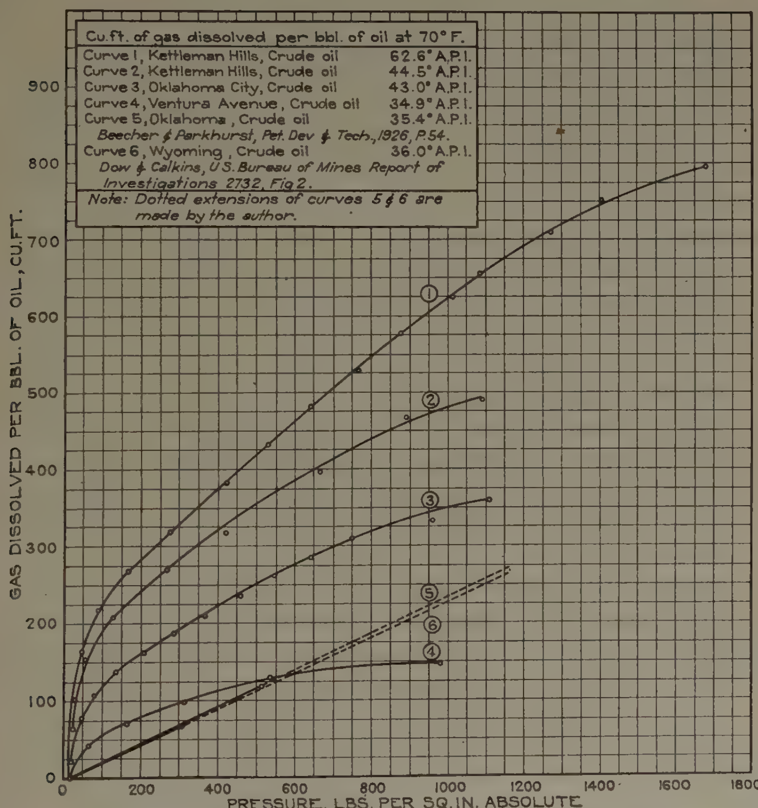

FIG. 2.—SOLUBILITY CURVES OF VARIOUS CRUDE OILS.

stopcock the second time (curve 1, Fig. 2), the pressure stabilized at 1263 lb. per sq. in. abs., and the third opening reduced it to 1079 lb. As the pressure in the bomb was reduced, the procedure necessarily was changed. At lower pressures the volume of the separator and the gage was not sufficient to produce a gas sample of suitable volume for complete analysis, as had been the case in the upper range of pressure. Therefore, to obtain a sample of sufficient volume for each successive pressure drop in the lower range, gas was drawn off slowly into the measuring bottles

for a considerable time under control of valve 6 with stopcock 1 open. Before taking final observations on the sample being drawn, however, valve 6 was closed. With the closing of valve 6, pressure within the closed-in system built up, as indicated by consecutive readings on gage *h*. The closed-in system was then allowed to stabilize. Stabilization was accelerated by violently hammering the bomb. This hammering also had the effect of preventing a supersaturated condition of the oil in bomb *a*. When the pressure became stabilized, stopcock 1 was closed, needle valve 6 opened slowly, and the gas under pressure in the separator assembly was drawn off and measured at atmospheric pressure in the manner applied to the upper range of pressures. In drawing off the final sample of gas in solution, the entire system was brought to atmospheric pressure with stopcock 1 and valve 6 open. The bomb was hammered violently.

The sum total of all of the gas given off at the different pressures was considered to be the total volume of gas originally in solution in the oil at the temperature and pressure under which the sample was taken at the well head. In arriving at amounts for calculation and for plotting curves to show pressure-solubility relationships, the actual total measured volume of gas was increased by an amount equal to the calibrated volume of the separator, the tubing connecting the separator with the measuring bottles and the shrinkage space above the oil in bomb *a* after the pressure was brought to atmospheric. The amount of gas in solution at any particular pressure could readily be obtained by subtracting the quantity of gas given off above that pressure from the total amount of gas given off in reducing the sample from the original well-head pressure to atmospheric. The gas-volume observations were reduced to a temperature base of 70° F. and a pressure of 14.4 lb. per sq. in. abs. A further correction was made for the presence of water vapor in the gas because the gas was constantly in contact with water in the measuring bottles. The combined correction factor for temperature, barometric pressure, and water vapor ordinarily varied between 0.87 and 0.94. In developing the solubility curves (Fig. 2), the reduction of volume of the oil due to the liberation of dissolved gas and the amount of gas under pressure occupying this shrinkage space above the oil was taken into consideration. At high pressures, especially, this made a considerable difference in the solubility curve. To explain: In reducing sample represented by curve 1, Fig. 2, from 1672 to 1396 lb. per sq. in. abs., the gas actually measured in the bottles and corrected for temperature, pressure and water vapor was 5665 c.c. In liberating this volume of gas, the oil reduced in volume approximately 1.5 per cent. The shrinkage space above the oil in the bomb was filled with gas at 1396 lb. pressure, which when expanded to atmospheric pressure would have amounted to about 932 c.c., neglecting its deviation from Boyle's law. The over-all effect of this deviation was within the limits of experimental error, therefore the total amount

of gas liberated between the pressure 1672 and 1396 lb. per sq. in. abs. was the sum of the gas volume actually determined in the bottles, separator and assembly, and the gas confined in the shrinkage space at the top of the bomb.

Shrinkage Determination

The following is a brief explanation of the method used in determining shrinkage:

1. The total shrinkage resulting from liberating the dissolved gases from any sample was obtained by measuring in a graduated glass cylinder the quantity of oil left in bomb *a* after the sample had been reduced to atmospheric pressure. Knowing the total capacity of the bomb, and the volume of oil remaining in it, the percentage of shrinkage was readily determined.

2. The shrinkage at any intermediate pressure was determined by obtaining a sample at well-head pressure, and instead of allowing the sample to stabilize at well-head pressure, its pressure was gradually reduced by opening valve 3 at the top of bomb *b*. If, for example, it was desired to determine the shrinkage at 400 lb. pressure per square inch, valve 3 was allowed to remain open until the pressure had reduced 50 or 60 lb. below the desired pressure. After closing valve 3, the pressure would be likely to build up to or above the desired pressure, and it would be necessary to vent more gas until the desired pressure was obtained. The sample would then be allowed to stabilize, and the procedure thereafter would be much the same as previously described. That is, the separator (Fig. 1*B*) would be substituted for bomb *b*, the gas would be drawn off into measuring bottles, and finally, when the sample was reduced to atmospheric pressure, the volume of the remaining oil in bomb *a* would be measured in a graduated glass cylinder. From this measurement, the shrinkage due to liberation of dissolved gases between the pressure of stabilization and atmospheric pressure could be determined. By taking several samples and stabilizing them at different pressures, a complete shrinkage curve, such as curve 1, Fig. 7, could be developed.

Handling of Gas Samples Prior to Analysis

In the California work the liberated gas collected in the sample bottles was transferred to 1-gal. oil-sample cans, sealed and shipped to the laboratories of the Bureau of Mines at Bartlesville, Okla., for analysis by fractional distillation at low temperatures. In the Oklahoma work, the bombs were transported from the field to the Bartlesville laboratories, where the gas was drawn off as described and the samples were allowed to remain in the calibrated measuring bottles until analyzed.

Results

Solubility

Curves 1, 2, 3 and 4 of Fig. 2 show the results of liberating the gas in solution from oil samples taken at well-head pressures and at a temperature of 70° F. These curves are selected for this preliminary report with the idea of offering data on oils covering the range of solubility factors, from almost the highest to the lowest determined. The oils also cover a wide range as to gravity and type.

Curves 5 and 6 are taken from the reports by Beecher and Parkhurst,[7] and Dow and Calkin,[8] respectively, for the purpose of comparing the results of this investigation with data formerly obtained on the solubility of gas in oil. The dotted extensions of curves 5 and 6 were made by the author.

A comparison of the curves in Fig. 2 shows the difference that exists between the data presented in this report and the results of former investigations. In the following discussion an attempt is made to explain some of these differences.

The foundation of most of the knowledge and thought relative to the solubility of gases in liquids is based upon the laws of Henry and of Dalton. According to Henry's law: "A given quantity of liquid will dissolve at constant temperature quantities (by weight) of the gas which are proportional to the pressure of the gas.[9] Dalton found that, "When a mixture of gases dissolves in a liquid, each component dissolves according to its own partial pressure, that is, each dissolves in the liquid as if all others were absent."[9]

It has been known for some time that these laws are not absolutely correct. Quoting from Taylor:[10] "Henry's law like other gas laws is strictly applicable only to ideally dilute gases and fails to represent the facts when the concentrations become large."

A clear illustration of the deviation from Henry's law is shown in Fig. 3, which was developed from laboratory experiments performed by Chalmers[11] and Nichols,[12] at the Petroleum Experiment Station of the Bureau of Mines, Bartlesville, Okla. It will be noted (Fig. 3) that the solubility curve of natural gas (curve 3) developed from the data of Mills

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[7] C. E. Beecher and I. P. Parkhurst: *Op. cit.*, 54, Fig. 2.

[8] D. B. Dow and L. P. Calkin: *Op. cit.*, curve 8, Fig. 2.

[9] Sir J. Walker: Introduction to Physical Chemistry, 50–51. McMillan and Co., Ltd. London, 1922.

[10] H. S. Taylor: A Treatise on Physical Chemistry, **1**, 470. D. Van Nostrand and Co., Ltd. New York, 1931.

[11] J. Chalmers, Petroleum Engineer, U. S. Bureau of Mines, Bartlesville, Oklahoma.

[12] D. Nichols, Assistant Petroleum Engineer, U. S. Bureau of Mines, Bartlesville, Oklahoma.

and Heithecker[13] is a straight line and therfore conforms to Henry's law, whereas curves 1 and 2 for propane and ethane, respectively, are curved lines and show a deviation from Henry's law. The deflection of these curves, however, is in direct opposition to the deflection of solubility curves 1, 2, 3 and 4 of Fig. 2. Therefore, obviously it is necessary to find some other explanation for the peculiar forms exhibited by the curves developed from data relating to the samples of gas-saturated oil which

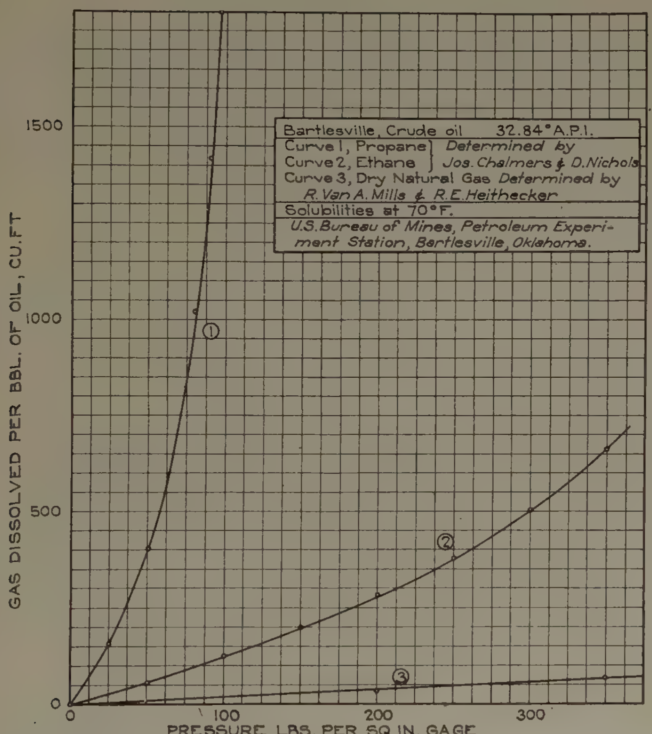

FIG. 3.—VARIATION OF SOLUBILITY WITH PRESSURE, BARTLESVILLE CRUDE OIL, 32.84° A.P.I.

were obtained at high pressure from flowing wells. It is not necessary to look far to discover at least a partial explanation for these deflections. Consider first the significance of Dalton's law: " . . . each component dissolves according to its own partial pressure . . ." Although this law may fail in accuracy at high pressures, the author believes that the analysis of its application, which follows, will serve to explain in a large measure the general trend of the solubility curves presented in this report. In conjunction with Dalton's law, a related factor, "selective solubility,"

[13] R. Van A. Mills and R. E. Heithecker: *Op. cit.*, 10, Table 3.

also must be taken into account. Consider, for example, the large quantities of natural gasol'ne that are often absorbed from comparatively dry natural gas by absorption oil in natural-gasoline plants. This concentration of heavy vapors is due to selective solubility. Fig. 3 shows that at 25 lb. per sq. in. gage the solubility factor expressed in cubic feet of gas per barrel of oil for propane is approximately 160, for ethane approximately 30, and for dry natural gas approximately 5.

For the purposes of discussion, assume a gas mixture containing 55 per cent. propane, 35 per cent. ethane and 10 per cent. dry natural gas similar to the natural gas of which the solubility is represented by curve 3, Fig. 3. These proportions are chosen by using as a guide the analysis of the gas liberated from solution in Kettleman Hills oil between pressures of 100 lb. per sq. in. abs. and atmospheric pressure. This analysis, as shown by the curves on Fig. 5, is approximately 10 per cent. methane, 35 per cent. ethane and the remaining 55 per cent. propane, butane and pentane.

The theoretical result of contacting 400 cu. ft. of this hypothetical gas mixture with a barrel of crude oil has been calculated by Chalmers and is shown graphically in Fig. 4. In these calculations, the solubility factors were determined from the curves shown in Fig. 3, and the gases were assumed to dissolve in the oil in accordance with Henry's and Dalton's laws.

If 400 cu. ft. of the specified gas mixture is contacted with a barrel of the crude oil used in the experiments recorded graphically in Fig. 3 (32.84° A.P.I. gravity), and if the solubility factors indicated by Fig. 3 are used, calculation based upon Henry's and Dalton's laws will show the results indicated in Fig. 4. The curves in Fig. 4 are not entirely dissimilar to those in Figs. 2, 5 and 6. Compare the solubility curve (curve 1, Fig. 4) with the corresponding curve (curve 1, Fig. 5). Fig. 5 is a graphical presentation of the results obtained from Kettleman Hills crude oil of 62.6° A.P.I. gravity. At 50 lb. per sq. in. gage pressure, the theoretical curve (curve 1, Fig. 4) shows a solubility of 113 cu. ft. of gas per barrel of oil, whereas at 65 lb. per sq. in. abs. (50 lb. gage) pressure, the Kettleman Hills oil shows a solubility of 193 cu. ft. of gas per barrel of oil. Solubility of the hypothetical gas-mixture factors at gage pressures of 100, 200 and 300 lb. per sq. in. is 205, 318 and 372 cu. ft. of gas per barrel of oil, respectively, as indicated by the theoretical curve, whereas from curve 1, Fig. 5, solubility at corresponding pressures is 235, 293 and 341 cu. ft. respectively. It is believed that the theoretical and actual solubility curves as shown in Figs. 4 and 5, respectively, conform closely enough to indicate that the solubility of gas in oil, plotted against the pressure, does not give a straight line throughout the entire range of pressures when the solubility is determined by measuring the gas released from an oil-gas mixture obtained under pressure from a natural reservoir.

In solving the foregoing hypothetical example, the results of which are shown graphically in Fig. 4, attention is called to the fact that the conditions stated were definite and limited; that is, the quantity of gas was 400 cu. ft. and the quantity of oil was 1 bbl. Similar conditions are found in nature; not necessarily in the same proportions, but certainly a definite amount of oil and a definite amount of gas exist in an undisturbed, natural oil reservoir. During geologic time these components

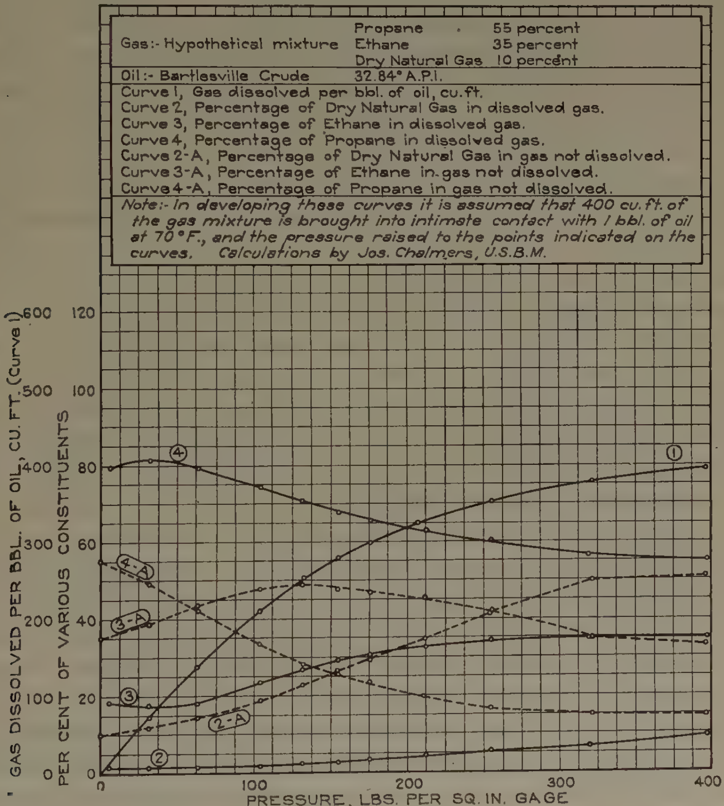

FIG. 4.—THEORETICAL SOLUBILITY CURVES.

reached a state of equilibrium. The gases that were capable of being absorbed under the definite conditions of temperature, pressure and ratio of the total quantity of gas to the total quantity of oil have long since been absorbed. The remainder of the gas, if there is an excess, remains associated with the oil but not dissolved in it.

It is important to consider these facts in defining and solving problems similar to that represented by Fig. 4. A study of the curves in Fig. 4 shows the selective solubility of the constituents of the hypothetical mixture at different pressures. For example, it will be seen that at 50

lb. per sq. in. pressure, 112 cu. ft. of the hypothetical gas mixture was in solution (curve 1). It is seen also that at 50 lb. pressure, 81 per cent. of the gas in solution was propane (curve 4). Therefore 91 cu. ft. of the total gas in solution at 50 lb. pressure was propane. By similar procedure it was found that an additional 62 cu. ft. of propane was in solution at 100 lb.; and of the remaining 67 cu. ft. of propane, all but 8 cu. ft. was in solution at 250 lb. pressure per square inch. The selective solubility of propane is well illustrated when these figures are compared with the amount of dry natural gas that was in solution at the same pressures. The figures for dry natural gas at these pressures are 1.5, 4.0 and 19.0 cu. ft. per barrel of oil, respectively (curve 3, Fig. 3). Thus at a pressure of 250 lb. per sq. in. gage, 212 cu. ft. of propane was in solution, whereas only 24.5 cu. ft. of dry natural gas was dissolved.

This selective solubility naturally changed the composition of the gas not in solution. It will be remembered that the hypothetical gas mixture originally contained 10 per cent. of dry natural gas, 35 per cent. of ethane and 55 per cent. of propane. Compare these figures with the analysis of the gas not in solution at 250 lb. pressure as indicated by curves 2-*A*, 3-*A* and 4-*A* of Fig. 4. This indicated analysis is: ethane 42 per cent., dry natural gas 41 per cent. and propane 17 per cent. Of course these calculated analyses are not strictly correct, for the reason that no correction is made for the effect of the vapor pressure of the oil. This correction, particularly for weathered oil, would be so small that it has been disregarded in the present hypothetical case.

In the theoretical problem dealing with a hypothetical gas mixture, no account has been taken of the changes in volume, specific gravity and other properties of the oil that occur progressively as the oil absorbs the gas. If the composition of liquid is changing progressively, dependent upon the properties of the gases which it absorbs because of selective solubility under pressure (and liquefaction under certain conditions), and, in turn, the contacted gases are changing progressively in composition, it would not be expected that as traight-line relationship would exist between the solubility of the gas mixture in the liquid and the corresponding pressures.

In comparing the results of the present investigation with those of other investigators, it should be realized that they measured the solubility of a gas, containing some hydrocarbons relativley high in the series, in oil composed of hydrocarbons relatively low in the series. The intermediate hydrocarbons, if present at all, were small in amount. Under these conditions and under the further condition that no definite limit was placed on the quantities of oil and gas used, it might be expected that the solubility curves, within the range of pressures used, would be straight, or nearly so. In the present investigation, the entire range of hydrocarbons was represented in the gas and liquid. Some of the hydro-

carbons that were gaseous under low pressure were in the liquid phase under high pressures.

In further explanation of the straight-line relationship, it may be well to consider the methods used where straight-line solubility curves were obtained. According to the published reports of these investigations, a new sample of weathered oil and a fresh sample of gas were used at each pressure point; and therefore the conditions of the tests reported by Beecher and Parkhurst and Dow and Calkin did not permit the progressive action of selective solubility. In other words, the gas that was put into solution at high pressures had the same constituents, in the same proportions, as the gas that was put into solution at low pressures. These conditions are not directly comparable with natural conditions in oil reservoirs, and therefore the oil-gas mixtures resulting from contacting oil and gas in the method described do not duplicate the oil-gas mixtures obtained under pressure directly from flowing wells.

Nature of the Gas in Solution

Curves 2, 3, 4, 5 and 6 (Figs. 5 and 7) show percentages of the various components of the gas in solution at various pressures. The curves in Fig. 5 indicate that the entire volume of gas dissolved at the maximum pressure contained 66.1 per cent. methane, 16.1 per cent. ethane, 11.3 per cent. propane, 5.2 per cent. butane and 1.3 per cent. pentane and heavier hydrocarbons.

The action of selective solubility is clearly illustrated when the curves are read at lower pressure. For example, if the curves are read on the 100-lb. ordinate, the following analysis of the dissolved gas is indicated: methane, 9.8 per cent.; ethane, 33.8 per cent.; propane, 35.3 per cent.; butane, 16.5 per cent.; pentane and heavier hydrocarbon, 4.6 per cent.

The effect of selective solubility is shown by curve 1, Fig. 5. At an absolute pressure of 100 lb. per sq. in., 230 cu. ft. of gas were in solution per barrel of oil, whereas at the maximum pressure of 1672 lb. per sq. in. abs., the gas in solution is not 16.72 times the quantity in solution at 100 lb. but only 3.48 times this amount, or 800 cu. ft. per barrel of oil.

Curves 2, 3, 4, 5 and 6 (Figs. 5 and 7) were developed from the results of the fractional-distillation analyses of the gas samples, liberated at the several observation pressures, to show the percentages of the constituents of gas in solution at those pressures. The total gas remaining in solution at any given pressure was considered to be 100 per cent., even though the actual volume of all of the components of gas in solution at that pressure may have been only a certain percentage (for example, 25, 33, or any other actual per cent.) of the total gas liberated throughout the entire pressure drop of the well-head sample from its initial pressure to atmospheric. The individual points for plotting the curve represent-

ing each component were obtained by arithmetical computations based upon the method of proportional parts.

The data shown in Fig. 5 may be presented in another way. In Fig. 6 the amounts of the various components of the gas in solution at any given pressure are plotted on the basis of cubic feet per barrel of oil instead of on the percentage basis used in plotting Fig. 5.

The oil represented in Fig. 5 has one of the highest solubility factors and the oil represented in Fig. 7 has one of the lowest solubility factors

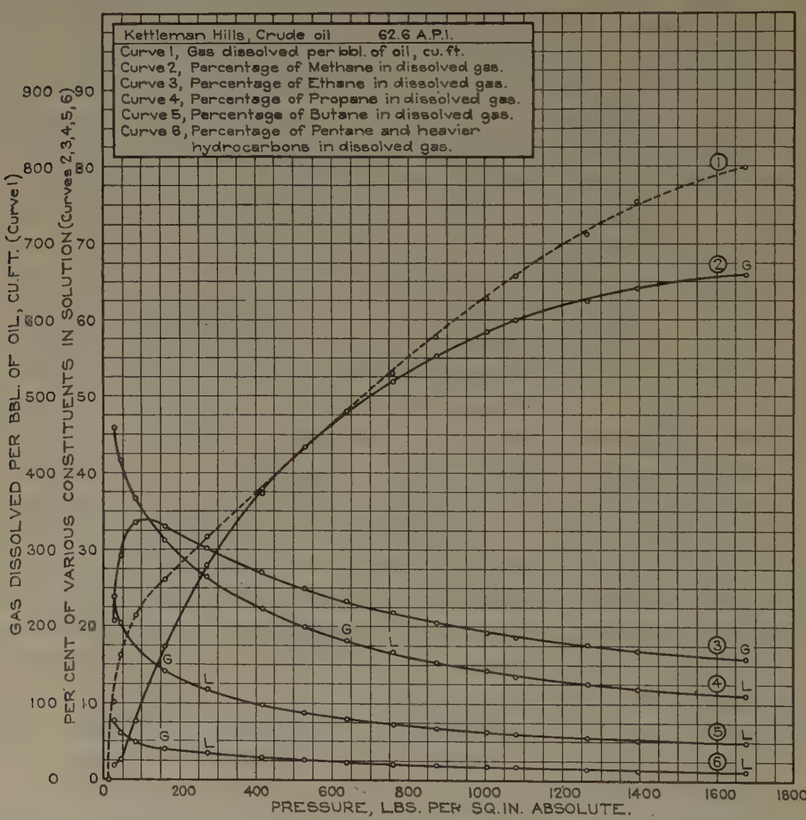

FIG. 5.—SOLUBILITY CURVES OF GAS IN SOLUTION AT 70° F. KETTLEMAN HILLS CRUDE OIL, 62.6° A.P.I.

of all of the oils tested. These charts have several interesting features. Attention is called to the peculiar reverse form taken by the ethane curve (3) at the 100-lb. ordinate in Fig. 5. Ethane is liberated in such large quantity at pressures below 100 lb. per sq. in. abs. that it might be thought to be changing from the liquid to the gaseous phase. This is not believed to be the case, however, as under the conditions of the test the partial pressure of ethane was below 573 lb., and therefore the ethane must have

been in the gaseous phase throughout the entire range of pressures. Hence, it is marked *G* (gas) at the maximum pressure. The heavier gases, however, are believed to have been in the liquid phase at the maximum pressure, as their respective partial pressures were sufficiently high to liquefy them at the existing temperature, 70° F. Propane remained a liquid until the pressure was reduced somewhat below 760 lb. per sq. in. abs. (curve 4, Fig. 5). The letter *L* indicates that it was in the liquid

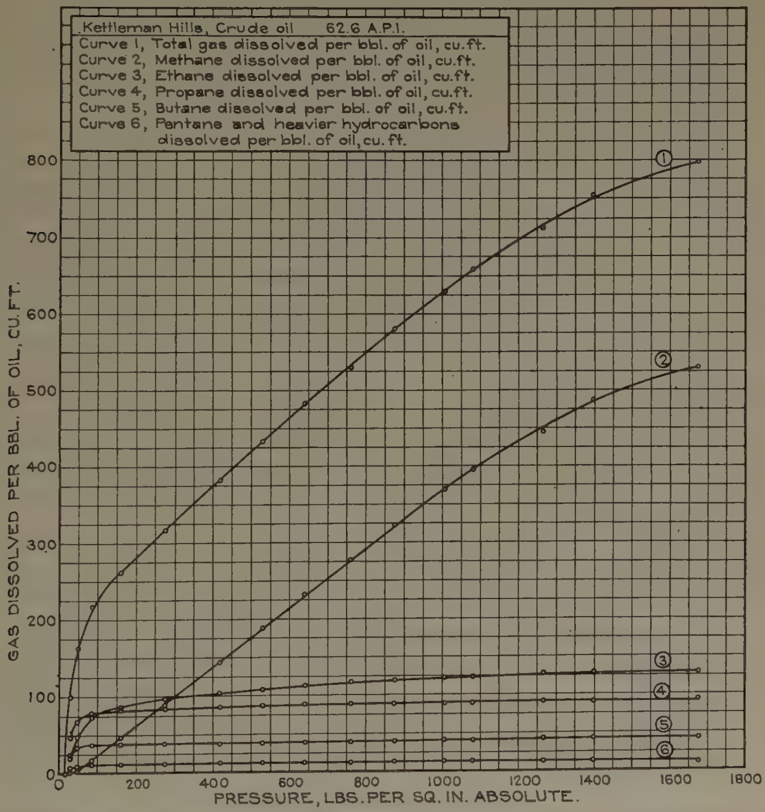

FIG. 6.—SOLUBILITY CURVES OF GAS IN SOLUTION AT 70° F. KETTLEMAN HILLS CRUDE OIL, 62.6° A.P.I.

phase at that pressure and the letter *G* indicates the gaseous phase at 640 lb. per sq. in. abs. Phase points *G* and *L* are also shown for butane and pentane, on curves 5 and 6 (Fig. 5), respectively. It was rather surprising to find that phase changes apparently have little effect upon the liberation of the various gas components. Possibly this is due to the fact that the various liquid hydrocarbons are infinitely soluble in each other—in other words, they are miscible in all proportions—and as the pressure on a hydrocarbon such as propane approaches the liquefaction pressure, the propane gas approaches "infinite solubility." Curve 1,

Fig. 3, seems to give credence to such an explanation. This curve tends to become vertical and therefore indicates infinite solubility as the pressure approaches 100 lb. per sq. in. gage, although propane would remain in the gaseous state at 70° F. until a pressure of approximately 109 lb. per sq. in. gage is reached.[14] It is quite possible that the ethane curve (2, Fig. 3) would show similar characteristics if its vapor pressure,[15] approximately 573 lb. per sq. in. abs. at 70° F., were approached. A

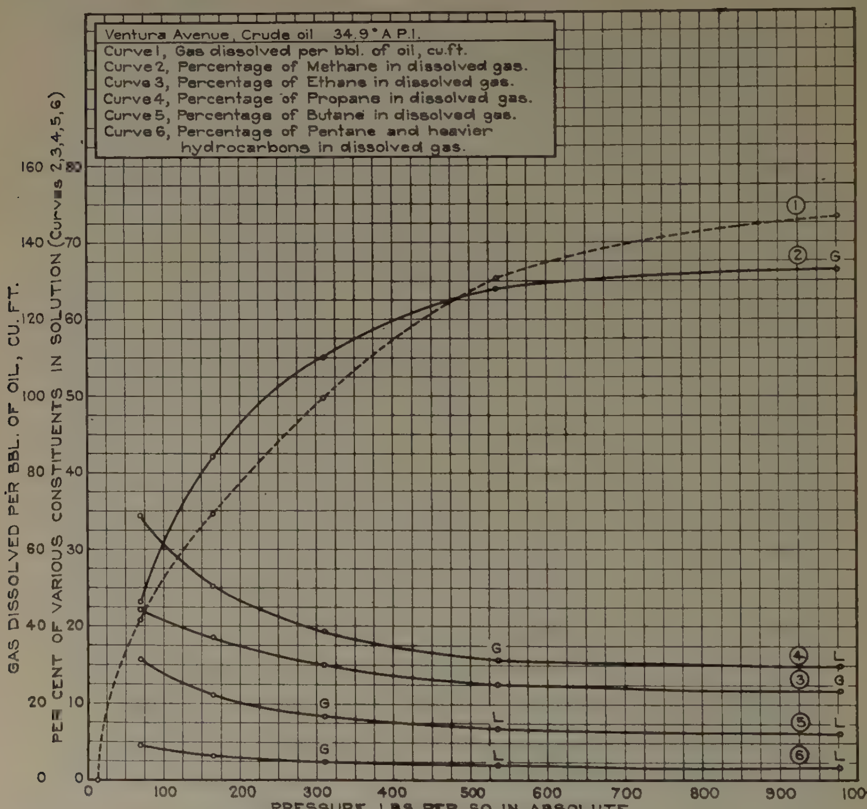

Fig. 7.—Solubility curves of gas in solution at 70° F. Ventura Avenue crude oil, 34.9° A.P.I.

study of curve 2, Fig. 3, shows that at a pressure of approximately 250 lb. per sq. in. gage this curve for ethane begins to deflect with an increasingly upward trend (its slope becomes greater with increased pressure), and if the pressure were increased to 550 lb. per sq. in. gage, it is believed likely that the curve might become nearly vertical. From the data shown in Fig. 3, however, there is no reason to believe that a methane curve would

[14] H. B. Coats and G. G. Brown: A Vapor-pressure Chart for Hydrocarbons Univ. of Mich. Dept. of Engineering *Circular*, Ser. 2 (December, 1928).

show an upward deflection, as the critical temperature of methane[15] is $-82.1°$ C. or $-116.2°$ F., and therefore, regardless of pressure, it could not approach liquefaction at 70° F.

One of the interesting features of Fig. 7 is that propane is in solution in greater quantity than ethane in the Ventura Avenue oil. This oil is the only one tested so far that has shown this peculiarity. Also, no reverse appears in the ethane curve for this oil, as was the case for the Kettleman Hills crude shown in Fig. 5. It is believed that such a reverse in the curve probably would have appeared if it had been practical to take gas samples at intermediate pressures between 68 lb. per sq. in. abs. and atmospheric pressure.

Shrinkage

Mills and Heithecker[16] have reported the results of their experiments relating to the changes in volume of certain crude oils due to the solution of gas in those oils. In their experiments, the oils contained hydrocarbons relatively low in the series, and the gas dissolved in the oils contained hydrocarbons relatively high in the series. As the intermediate hydrocarbons, if present at all, were in relatively small amounts, it is not surprising that straight-line shrinkage curves were obtained as shown by curve 3, Fig. 8. Curve 4, Fig. 8, is a straight line of the same slope as curve 3; it was plotted from the 100 per cent. point at 1672 lb. per sq. in. abs. for Kettleman Hills crude of 62.6° A.P.I. gravity.

Curve 1, Fig. 8, shows the volumetric changes at various pressures undergone by Kettleman Hills oil when its dissolved gas was liberated from 1672 lb. pressure per square inch absolute to atmospheric pressure. Its volume at the maximum pressure is assumed to be 100 per cent. It is well to point out here that extreme accuracy is not vouched for in these shrinkage determinations, as the apparatus (Fig. 1) was not designed for this purpose, and it was only through arduous and complicated procedure that H. C. Miller[17] and the writer obtained the approximate data shown by curves 1 and 2, Fig. 8.

Curve 1, Fig. 8, shows that a well-head sample of Kettleman Hills crude oil of 62.6° A.P.I. gravity sustained a loss in original volume of approximately 36 per cent. when the pressure was reduced from 1672 lb. per sq. in. to atmospheric. During this reduction in pressure, at a constant temperature of 70° F., an equivalent of 800 cu. ft. of gas per barrel of oil was liberated (curve 1, Fig. 5). Although true bottom-hole conditions of pressure and temperature in the well from which the sample

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[15] International Critical Tables. Vol. 3, p. 230.

[16] R. Van A. Mills and R. E. Heithecker: *Op. cit.*

[17] H. C. Miller, Senior Petroleum Engineer, U. S. Bureau of Mines, San Francisco, California.

was taken (or adjacent wells) are not known, it is not unreasonable to suppose that withdrawal of gas from solution in the reservoir will cause a reduction in volume of the liquid content of that reservoir which is comparable, and of the same order, with the results obtained in the present oil shrinkage study. If the above assumption is true, and knowing that 800 cu. ft. of gas was liberated per barrel of 62.6° A.P.I. gravity in a pressure reduction of well-head samples from 1672 lb. per sq. in. to atmospheric, it could then be said that the total liquid content of the reservoir will have been reduced in volume approximately 0.36 bbl. for each 800 cu. ft. of gas

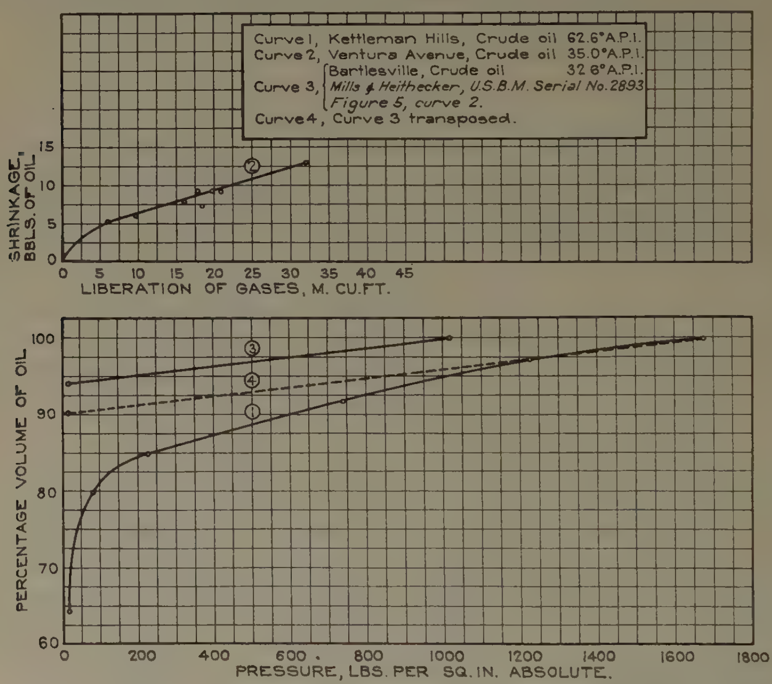

FIG. 8.—SHRINKAGE OF OIL DUE TO LIBERATION OF DISSOLVED GASES.

liberated from solution within the pressure range covered by the experimental work. This amount of shrinkage would be in addition to the depletion that can be measured in actual barrels of oil produced. The full significance of this shrinkage factor in computing normal decline and ultimate production of natural reservoirs which are under so-called volumetric control has not yet been determined.

It was necessary to plot curve 2, Fig. 8, of the Ventura Avenue crude on an entirely different basis from that used in plotting curves 1 and 3, because of the wide variation in the solubility factors of this oil at virtually the same pressures. This variation in solubility probably was due to the fact that the well flowed by heads with a variation in pressure of more

than 200 lb. per sq. in. during the process of taking an oil sample. The maximum pressure of 977 lb. per sq. in. abs. for the Ventura Avenue sample (curve 1, Fig. 7) is the pressure of stabilization after the bomb was disconnected from the well. Actually during the progress of taking this and other samples of Ventura Avenue oil, the well pressure at times went below and above the final pressure of stabilization. However, the pressure recorded was probably more constant than any other pressure observed during the sampling period.

Curve 2, Fig. 8, shows that for each 32,000 cu. ft. of dissolved gas that is liberated from this oil, within the range of pressures covered by the experimental work, there is indicated a possible shrinkage of at least 13 bbl. of liquid content of the reservoir, in addition to the depletion caused by the oil produced. Curve 2, Fig. 8, also brings out a fact that is not shown directly in curve 1, Fig. 8. It shows that equal volumes of dissolved gas do not result in equal volumetric changes in the oil; for example, 5000 cu. ft. of the heavier gases occupy a space equal to 5 bbl., or roughly, an equivalent of 24 cu. ft. per gallon. Comparison of the upper and lower ranges of this curve indicate that the oil shrinkage due to the liberation of the lighter gases is about one-third that of the heavier gases. This condition probably can be explained by the fact that the molecules of the heavier gases are composed of a greater number of atoms than the molecules of the lighter gases, also, they are actually larger in size and therefore occupy more space when in solution than do an equal number of molecules of the lighter gases. When out of solution, however, equal numbers of molecules of different gases occupy the same space when under the same temperature and pressure in accordance with Avogadro's law.

Gravity of the Oil

The gravity of the gas-saturated oil under pressure was not observed. However, it is not particularly difficult to arrive at an approximate value for this figure, by estimating the weight of the various gas constituents liberated. A gram-molecule of any gas has a volume of approximately 22.4 liters at 0° C. and 760 mm. At 70° F. and 14.4 lb. pressure per square inch absolute, this volume would be 24.63 liters. Knowing the volume of the various components liberated, their combined weight in grams can be calculated. Also by knowing the volume of the bombs, which were filled originally with gas-saturated oil, and the volume and specific gravity of this oil when reduced to atmospheric pressure at 70° F., the weight of the original gas-saturated oil sample is the sum of the weights of the gas liberated and the oil recovered. Its specific gravity can be determined by dividing the weight of the gas-saturated oil in grams by its volume in cubic centimeters.

Such calculations have been made with reference to the oils represented in Figs. 5 and 7, and results are shown in Table 1.

Table 1.—*Estimate of Gravity of Gas-saturated Crude Oil*

Kind of Oil	Gravity, Deg. A.P.I. at Atmospheric Pressure	Gravity of Gas-saturated Oil at Well-head Pressure, Deg. A.P.I. (Computed)	Well-head Pressure of Gas-saturated Oil, Lb. per Sq. In. Abs.
Kettleman Hills..........	62.55	102.30	1672
Ventura Avenue..........	34.87	38.94	977

It is interesting also to compare the gravity of the oils recovered after the dissolved gas had been liberated gradually to atmospheric pressure, with the gravity of these oils, as reported by the operators. Table 2 shows this comparison.

Table 2.—*Effect of Rate of Liberating Dissolved Gases upon the Gravity of the Oil*

Field	No. of Samples	Average Gravity of Oil Recovered in Experiments, Deg. A.P.I.	Gravity Reported by Operators, Deg. A.P.I.
Kettleman Hills..........	7	63.1	61.0
Kettleman Hills..........	5	44.8	40.0
Ventura Avenue..........	8	35.0	32.0
Oklahoma City..........	2	43.0	39.9

The higher gravity resulting from gradual reduction of pressure is undoubtedly due to the retention by the oil of part of the propane fraction, large quantities of butane and pentane, and possibly some of the heavier hydrocarbons, which in field operations usually are carried away by a rapidly moving stream of gas when the pressure is released suddenly within the system. A system of trapping that would accomplish gradual separation at the highest possible pressures might be the means, under certain conditions, of not only increasing the value per barrel of the oil produced but also of increasing the quantity of oil by causing it to retain certain hydrocarbons which under ordinary trapping systems would become a part of the gas.

Nature of Gas Not in Solution at High Pressures

A sample of gas was taken from the delivery valve 3 of the upper bomb *b* (Fig. 1) during one of the tests on the well at Kettleman Hills for which solubility curves are given in Fig. 5. This sample of gas is believed to be representative of the free gas that was not dissolved in the oil at a pressure of 1672 lb. per sq. in. abs. and 70° F. The following is its analysis: methane, 85.6 per cent.; ethane, 8.0 per cent.; propane, 3.6 per cent.; butane, 1.7 per cent.; pentane and higher, 1.1 per cent.

By calculation, based upon field data not included in this present report, it has been estimated that the quantity of gas not in solution at a pressure of 1672 lb. per sq. in. abs. and 70° F. was equal to approximately 95.4 per cent. of the total gas delivered by the well; also, other calculations indicate that this 95.4 per cent. portion of the gas which was undissolved under the stated conditions contained approximately 91 per cent. of total butane produced by the well.

Calculations have been made for the purpose of estimating the amount of natural gasoline contained in the gas not in solution at a pressure of 1672 lb. per sq. in. absolute and 70° F. These calculations take into account the heavier fractions contained in the "pentane and higher fraction" and also take into account the fact that the final natural gasoline product which is produced in plant operation must not contain more than 31 per cent. butane. The results of these calculations indicate that the gas not in solution at 1672 lb. per sq. in. abs. and 70° F. contained approximately 0.411 gal. of pentane and heavier hydrocarbons per 1000 cu. ft. and 0.326 gal. of butane per 1000 cu. ft.; or, such gas contained a total of approximately 0.737 gal. of natural gasoline per 1000 cubic feet.

General Statement

The results of this investigation show the solubility of gas in certain crude oils at various pressures from 1686 lb. per sq. in. abs. to atmospheric, and at a temperature of 70° F. They do not show the solubility at the very high pressures which may exist underground and at temperatures of possibly 200° F. or more which have been indicated by geothermal studies. Whether the solubilities existing underground are greater or less than those shown in Fig. 2 is not known. It is known, however, that increased pressure increases the solubility of gas in crude oil, and that within certain limits increased temperature decreases the solubility. It is known also that in distillation an increase in temperature results in the liberation of dissolved gases, and portions of the oil that are liquid at lower temperatures are vaporized at higher temperatures. In comparing the effect that experimental conditions had upon the results reported in this investigation with the effect that might be obtained if the experimental conditions approximated natural conditions more closely, the partly counteracting influences of increased pressure and of temperature must be considered. Higher pressures closely approximating those existing underground would cause more gas to be in solution in the oil (or to be in the liquid state) than the results obtained from well-head samples at flowing pressures have indicated. The effect of higher temperatures upon the solubility of natural gas in crude oil would be to decrease the amount in solution of the less soluble gases, methane for example, and to increase the liberation of the more soluble gases, propane and butane,

that remain in solution in considerable quantity when a sample is reduced to atmospheric pressure at a temperature of 70° F. That these more soluble gases remain in solution in considerable quantity at atmospheric pressure and temperature is indicated in the introduction of this paper, where reference is made to the quantity of gas liberated by applying vacuum to Burbank crude oil. In addition to the increased liberation of the more soluble gases, certain hydrocarbons that would be in the liquid state at 70° F. would be vaporized at higher temperatures.

An estimate of the combined effect of these several and presumably counteracting factors upon solubility, shrinkage and amount of recoverable vapor when samples are reduced to atmospheric pressure under different temperature conditions is not attempted in this preliminary report.

Acknowledgment

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Members of the U. S. Bureau of Mines who have rendered valuable aid either in the field or in the laboratory are: H. C. Miller, senior petroleum engineer, San Francisco, Calif., H. M. Smith and assistants, E. C. Lane and assistants, O. C. Blade, C. R. Bopp and Gustav Wade, all of the Bartlesville Station, Bartlesville, Okla.

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The investigation has been conducted with the hearty approval of H. C. Fowler, acting chief petroleum engineer, U. S. Bureau of Mines, Washington, D. C., and under the direct supervision of N. A. C. Smith, supervising engineer, U. S. Bureau of Mines, Bartlesville, Okla.

DISCUSSION

(*C. E. Beecher presiding*)

H. H. Power,* Tulsa, Okla. (written discussion).—This preliminary report of investigations of the solubility of natural gas in crude oil presents relationships

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between the amount of gas in solution in the oil and temperature and pressure conditions within the reservoir, which differ materially from those shown by Beecher and Parkhurst, Dow and Calkin, and others.

1. The straight-line relationship between pressure and absorbed gas at any given temperature does not hold when selective solubility of the various hydrocarbons under reservoir conditions takes place. Any extrapolation of straight-line relationships at the lower pressures will not hold.

2. Shrinkage of the crude oil upon loss of gas absorbed in the oil under high pressures may constitute a material loss in recovery in addition to ordinary depletion of oil reserves.

3. High-pressure traps in series may be so designed as to effect gradual separation at the highest possible pressures. The experimental work shows that the higher gravity resulting from gradual reduction of pressure is attributable to retention of part of the propane fraction, large quantities of butane and pentane, and possibly some of the heavier hydrocarbons in the oil. With a trap pressure of 1672 lb. per square inch, 95.4 per cent. represented the proportion of total gas delivered by the well, not in solution below trap pressure. Of this 95.4 per cent., the butane content amounted to 0.3255 gal. per 1000 cu. ft., and the pentane and heavier content amounted to 0.411 gal. per 1000 cu. ft. This gave a total of 0.737 gal. per 1000 cu. ft. as the gasoline content of gas not in solution below 1672 lb. trap pressure, and at a temperature of 70° F. An actual test by the operators showed that the gas being produced from the high-pressure traps contained 0.98 gal. per 1000 cu. ft. The difference between 0.98 and 0.737, or 0.243 gal. per 1000 cu. ft., represented the additional natural gasoline retained in the sample of oil collected in the bomb as compared with the oil collected in the high-pressure traps under normal operating conditions.

Hence a system of trapping eliminating abrupt pressure differentials and effecting gradual separation at the highest possible pressures might increase the gravity and consequent price of the oil, and also increase the quantity of oil due to retention of hydrocarbons which might otherwise become a part of the gas. However, owing to the low boiling point and volatility of the butane fraction, the benefits incident to its retention in the oil may be open to question. The oil gravity may be maintained at sufficiently increased gravity to realize an increased price from the pipe line company, but the refinery may have as little use for butane as does the casinghead gasoline manufacturer. However, the importance of retaining the pentane and heavier hydrocarbons in the oil is more readily recognized. Actual tests under existing well-head pressures, and calculations made in the light of prevailing economic conditions, should enable operators to decide whether maximum profits are obtainable on one hand from maintenance of the highest possible gravities in oil produced or, on the other hand, from maximum prices received from casinghead gas in relation to gasoline content.

The continuation of such studies as Mr. Lindsly has undertaken should have widespread application in the field of petroleum engineering. At the present time no more important problem confronts the industry than the interpretation of oil recovery rates, potentials, and effect of various expulsive agents, in terms of reservoir pressures and pressure differentials existing between such reservoir pressures and the bottom of the hole, and the top of the well. Inasmuch as oil and gas samples may be obtained under conditions closely approximating those originally in the reservoir at time of well completion, the method outlined in this report may be utilized, and the relationships between pressure, volumes, and analyses of gas, worked out in the beginning for all succeeding drops in pressure in the future life of the well. Since the proportions of various hydrocarbons are governed by prevailing pressures, it might be conceived that subsequent analyses of gas should throw considerable light on reservoir and operating well pressures. In other words, it is possible that methods may be worked out whereby the efficiency of recovery may be controlled to a considerable

extent by a proper interpretation of gas analyses taken from time to time in the decline of the well.

Another factor entering into the gravity of the oil is the operating method employed. It is possible to conceive that too rapid production of oil from the reservoir to the well head may have the same effect on gravity as too rapid separation. Hence we may have another argument for pressure-controlled production. Means taken to check the velocity of the oil and gas mixture from well bottom to top, and maintain production at the smallest pressure differential possible, may result in crude of higher gravity, and consequent higher prices received from the pipe line companies.

In the evaluation of items entering into the economic possibilities of a casinghead gasoline plant, perhaps two of the most difficult factors to appraise are: (1) the probable future production of casinghead gas from the properties supplying the plant, and (2) the probable gasoline content of this gas at various intervals in the lives of the properties up to their economic limit of production. Methods of appraisal have been standardized whereby future casinghead gas reserves may be estimated. However, in order to anticipate the probable future gasoline content of the gas the method employed in this report might be used. An analysis of gas obtained by means of pressure bombs under reservoir conditions, made at date of appraisal by the drop in pressure method, should afford a basis for anticipating gasoline content to be expected under various future declines in rock pressure. The gas vented from the bomb at any given drop in pressure should have an analysis comparable, at least to a significant degree, with the analysis of the casinghead gas from the well at a future time when rock pressures decline from similar amounts to similar smaller amounts.

C. E. Beecher* and D. B. Dow,† Bartlesville, Okla. (written discussion).—Mr. Lindsly has presented some extremely interesting and important data pertaining to the solubility of gas in oil. We sincerely hope that the Bureau of Mines can continue experiments of this character and if possible get similar data pertaining to the condition of oil and gas in the bottom of the well.

The data indicate, as shown on Fig. 2, that a large volume of gas is dissolved in the oil as it comes from the well and that the solubility curve is not a straight line. The character of the curve at pressures below 200 lb. we believe is due to the large percentage of propane, butane and pentane present in the gas. Above this pressure the solubility curves approach a straight line for a short distance and then curve in a direction to indicate a decreased rate of solubility. Since methane constitutes the major portion of the gas at the higher pressures we should anticipate a straight-line relation and do not have a satisfactory explanation for the deviation. We hope that future experiments will clear up this point.

It is obvious that Mr. Lindsly's sample of oil taken at the well head contains gas, gasoline vapors, etc., which have contributed no part at all in the movement of oil from the sand to the hole, nor has this gas contributed toward lifting the oil from the bottom of the hole to the top other than the effect it may have had on the viscosity of the oil, since gas that remains in solution has had no opportunity to expand and do work. Consequently, this discussion is limited to gas in solution, which has contributed no part toward the production of the oil. The movement of oil to the hole and from the bottom of the hole to the top was accomplished entirely by pressure within the reservoir and due to work expended by free gas in the reservoir and gas which came out of solution in the sand and in the flow string. Undoubtedly, the gas that did the work would be largely methane, a small amount of ethane and only very small percentages of propane, butane, etc.

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* Empire Companies.

† Indian Territory Illuminating Oil Co.

A large percentage of the total gas recovered consists of ethane, propane, butane and pentane. These gases, with the possible exception of ethane, are believed to exist in a liquid state under the formation or rock pressures and as such would have little effect in producing a movement of the oil through the sand. They would, however, have a greater bearing upon the viscosity of the oil because they are miscible with the oil in all proportions. It is entirely possible that the viscosity of the oil in the sands approaches that of kerosene. Methane, however, does not liquefy at any temperatures or pressures encountered in the oil-bearing formations and therefore we consider it together with some ethane as being the chief propulsive agency that moves the oil through the sands to the wells and flows the oil to the surface. If the pressures are reduced sufficiently within the flow string it is possible that the other gases play some part in lifting the oil, but we are inclined to believe, from the information that is available on the subject, that their part is very small. It is the purpose of this discussion to show that the volumes of methane and ethane in the gas are the important factors to be considered from a recovery standpoint, or from a standpoint of the energy available for moving the oil through the sand and lifting it to the surface.

Mr. Lindsly has pointed out one important fact pertaining to the shrinkage of oil due to the liberation of dissolved gases. An inspection of the curve shown at the bottom of Fig. 8 again emphasizes the fact that the heavier gases, such as propane, butane, etc., account for a large percentage of the shrinkage loss. For example, the loss in volume between atmosphere and 200 lb. pressure is approximately 20.5 per cent., while the total loss is 36 per cent., or a loss of 15.5 per cent. between 1670 and 200 lb. As stated by Mr. Lindsly, this percentage loss is an extremely important item that should be taken into consideration when making estimates of reserves. The magnitude of this shrinkage is certainly surprising.

It is pointed out that the volume of gas in solution in the formation will vary considerably from the samples taken because of the greater pressure and temperature, temperature having the tendency to decrease the solubility while pressure increases the solubility. From the little information available, it is our opinion that the increased pressure will more than offset the increase in temperature. For example, the sample of the Kettleman Hills oil as taken by Mr. Lindsly had a pressure of about 1670 lb. and a temperature of 70° F. We estimate that the oil would contain a much larger volume of gas at the rock pressure of around 3000 lb., regardless of the fact that the temperature might be 200° F. We quote the following figures taken from the results of an experiment that was not too carefully conducted, but it indicates a condition which we believe would be analogous to the one under discussion. At a pressure of 400 lb. and a temperature of 50° F., 90 cu. ft. of a natural gas dissolved in 1 bbl. of oil. A similar test was conducted at the same pressure but at a temperature of 110° F. Under these conditions 70 cu. ft. of gas dissolved in a barrel of oil. The temperature was increased 120 per cent. while the pressure remained the same, but the decrease in solubility was only 30 per cent. This, we assume, would indicate that pressure is more important than temperature, other conditions being equal, and assuming temperatures of not over 200° F.

B. E. Lindsly (written discussion).—The point brought up by Mr. Power regarding the possibility of applying the data obtained from high-pressure oil and gas samples to the evaluation of natural gasoline projects is novel and therefore particularly interesting. The author does not know to what extent such possibility might become an actuality. Raoult's law gives a quantitative relationship at various conditions of temperature and pressures between the individual components in a liquid mixture, and the corresponding components of the gas mixture in contact with the liquid. If this law holds within reasonable accuracy for hydrocarbon mixtures, it would seem that the

data obtained from high-pressure samples of oil and gas in the early life of a field compared with similar data a year later, when the pressure is somewhat reduced, might be the means of predicting the quantitative as well as the qualitative relationship between the total liquid content of a pool and the total quantity of free gas. Such a step, however, is so far in advance of the present study that the author hesitates at the present time to make a definite statement regarding the feasibility of such a scheme.

Regarding the flattening out tendency in the upper pressure ranges of the solubility curves, the author is in agreement with Messrs. Beecher and Dow. It would be expected that these curves would tend to approach a straight line at high pressures, also that this line would approach the slope of a solubility curve of pure methane in the particular solvent under consideration. Curve 1, Fig. 4, which is the development of a hypothetical example, indicates this. It is hoped that a more intensive study of the experimental data and of laws other than Dalton's and Henry's will develop an explanation of what appears now to be an unreasonably large decrease in solubility in the upper pressure ranges.

The author does not fully concur in the statement that the heavier gases such as butane have contributed "no part at all in the movement of oil from the sand to the hole" nor "toward lifting the oil from the bottom of the hole to the top." The solubility curves cannot be considered to represent, at lower pressures, the condition of the oil underground at similar lower pressures. In explanation of this, it should be realized that the oil in a natural reservoir is continually in contact with the reservoir gas, which under nearly all conditions of pressure contains a very large percentage of methane. This methane has the effect of reducing the partial pressures of the heavier gases such as butane. Therefore with its partial pressure reduced, more butane will be liberated from solution in the reservoir oil at a given lower pressure than would be liberated from solution at a similar pressure in the experiments. Also, the effect of the higher temperature in the reservoir as compared to the test temperature would tend to cause the heavier hydrocarbons such as butane to act more nearly like gas. These are qualitative statements based on Raoult's law. The application of Raoult's law has not been considered in this preliminary report, but it is believed that there are sufficient data to make good use of this and other laws, and that future study will more nearly reflect the effect of these heavier gases on the propulsion of oil in the sand.

Messrs. Beecher and Dow have brought out an important point relative to the greatly reduced viscosity due to the large amounts of gas dissolved in the crude oil. This reduced viscosity is indicated in Table 1, where it is shown that the A.P.I. gravity is greatly increased by the gases dissolved in the oil.

The point brought up by Messrs. Beecher and Dow regarding shrinkage is also important. The author believes that the shrinkage curves in Fig. 8 are minimum values, for the reason that the samples of oil, which were reduced to atmospheric pressure under the conditions of the test, were considerably higher in gravity than the oil produced in the field. Obviously, if the samples had been brought down to the same gravity as the pipe line oil (by means of vacuum or by the application of heat), greater quantities of gases and vapors would have been given off and these gases would have resulted in greater shrinkages than those shown in Fig. 8.

Some Principles Governing the Choice of Length and Diameter of Tubing in Oil Wells

By J. Versluys,* The Hague, Netherlands

(Tulsa Meeting, October, 1930)

A well can flow exclusively through the casing or exclusively through a tubing but can also flow partly through a casing and at the top part through a tubing. The main principles of the flowing of wells under these conditions were explained in the author's former paper.[1] Practically all factors that influence the regular flow are dealt with therein. The question of irregular flow, however, will be discussed briefly here. As a rule, an irregular flow must be avoided, as it may be assumed that the efficiency is thereby very small, while on many fields it is injurious to the sand of the oil-bearing layer.

Periodical flowing often occurs with rising mixtures of gas and liquid. The phenomenon can be explained if it is accepted that two conditions are possible in the mixture; namely, the foam condition and the mist condition.

If there is no stabilizer in the liquid, the foam condition can exist only when the liquid forms a greater portion of the volume than the gas. The mist condition, on the other hand, can exist only when the liquid occupies a smaller part of the volume than the gas. The foam condition occurs when there are gas bubbles in the liquid mass, while in the mist condition drops of liquid are disseminated in a gas-filled space.

For sake of simplicity, it has been assumed that the mist condition prevails when 50 per cent. or more of the volume is occupied by gas, while with less than 50 per cent. gas the foam condition will arise. For distilled water and for oils which do not tend to form stable foams this is probably approximately true. If this does not hold good, however, two cases are possible: (1) The fields of the two conditions overlap or (2) they do not meet.

If the fields of the conditions overlap there is an intermediate field where either of the two conditions can exist, depending on the history of the mixture. Suppose the foam condition prevails first and the gas

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[1] J. Versluys: Mathematical Development of the Theory of Flowing Oil Wells. *Trans.* A. I. M. E., Pet. Dev. and Tech. (1930) 192.

expands; in this event the foam will break and the liquid will disperse as soon as the ultimate proportion of gas in the mixture has been obtained. Owing to the overlapping of the two fields the mist condition, which has arisen through the breaking of the foam, will persist. If on the contrary the mixture is under the mist condition first, and it is compressed, the conversion to the foam condition will take place only when the gas volume has so far decreased that the limit of mist condition is reached. Due to the overlapping, the new condition will not be disturbed.

If the fields of mist and foam conditions do not meet, however, there is no sudden conversion if the volume ratio of the two substances gradually changes, whatever the history of the mixture may be. If we start with the foam condition and the gas expands when the limit of this condition is reached, the foam will break but there is not yet sufficient gas to allow of the existence of the mist condition throughout the mass. Probably the mixture will dissociate; that is, it will be converted into a mixture of small bodies of foam and of mist. Not until the gas has sufficiently expanded to allow of the mist condition throughout the mass will the foam entirely disappear.

In the former considerations, however, the tendency of the two substances, gas and liquid, to segregate, because of the great difference in their specific gravities, has been disregarded. This would be correct only with a very intimate mixture; that is to say, with very small bubbles of gas or very fine drops of liquid.

The dispersion of gas in liquid (the foam condition) or of liquid in gas (mist condition) generally is not such as to make the particles (either the bubbles or the drops) so small that the bubbles will not rise and the drops will not sink at an appreciable rate. This question of the segregation of the two components, gas and liquid, the effect of which is neutralized by the continuous rising of the mixture in a channel, is of vital importance in considering the flow conditions in a channel. The result is that the gas always has a greater velocity than the liquid. Gas bubbles will endeavor to rise in the heavier liquid under all circumstances, while drops of liquid distributed in a gas will always have a tendency to drop. In the foam condition the difference in velocity is small, while in the mist condition it is large.

It appears from experiments made by J. S. Owens[2] that gas bubbles rise in oil at a rate of about 8 in. per second. In water the average velocity is approximately 12 in. per second. Investigations made by Lenard[3] have demonstrated that the velocity of the fall of drops of water in air can be as follows:

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[2] J. S. Owens: Experiments on Air-lift Pumping. *Engineering* (1921) **112,** 458–461.
[3] P. Lenard: Ueber Regen. *Meteorologische Ztsch.* (1904) **21,** 249–262.

Diameter of Drops, Millimeters	Maximum Velocity of Fall, Feet per Second	Diameter of Drops, Millimeters	Maximum Velocity of Fall, Feet per Second
0.01	0.01	1.5	19.0
0.02	0.04	2.0	19.7
0.03	0.10	2.5	21.3
0.05	0.27	3.0	23.0
0.1	1.0	3.5	24.7
0.2	4.3	4.0	25.9
0.3	9.0	4.5	27.0
0.4	11.0	5.0	27.0
0.5	12.0	5.5	27.0
1.0	15.0		

Rising air should have the following velocities in order to entrain drops of water:

Diameter of Drops, Millimeters	Velocity of Rising Air, Feet per Second
1.28	16.0
3.49	24.6
4.50	27.0
5.47	26.6
6.36	26.0

Figures were found by W. Schmidt[4] which do not differ to any appreciable extent from those found by Lenard.

A result of the difference in velocity is that the proportion in which gas and liquid are mixed when the mixture rises is different from that in which they flow through. The liquid always moves more slowly and each particle of liquid remains longer in a certain part of the traject than does a particle of gas.

This can be conceived as follows: Suppose pedestrians and motor cars are moving along a road in the same direction at such a rate that one pedestrian and one motor car pass a certain point each minute, there will always be 15 pedestrians and 1 motor car in a stretch of 1 mile if the former have a speed of 4 miles and the latter a speed of 60 miles. per hour. The ratio of the flow is then 1/1 and the ratio of the mixture is 15/1. Therefore the proportion in which liquid and gas are mixed is always more to the advantage of the liquid (the slowest) than that in which the two substances flow through, and a large difference in velocity with one and the same ratio of flow will change the ratio of the mixtures more to the advantage of the liquid than a small difference in velocity.

The ratio of mixture depends on both the ratio of flow and the difference in velocity and also on the absolute velocity. This is a point

[4] W. Schmidt: Eine unmittelbare Bestimmung der Fallgeschwindigkeit von Regentropfen. *Meteorologische Ztsch.* (1909) **26**, 183–184.

of great importance; the ratio of mixture determines which condition will occur—the foam condition or the mist condition—but each of these conditions has its own difference in velocity, and the difference in velocity has a great influence on the ratio of mixture. As will be seen below, the consequence of this is that with a certain velocity of rise of the mixture and with certain ratios of flow, neither the foam condition nor the mist condition is actually possible.

If a mixture of gas and liquid rises in a vertical channel the pressure decreases and the gas expands in consequence. As a result of this the ratio of the flow and also the ratio of the mixture change. But the velocity of the mixture also becomes greater. The decrease in pressure has also, therefore, an indirect influence on the ratio of the mixture because the volume of the gas becomes greater when there is a decrease in pressure, so that the velocity increases. This second, indirect influence is not as great as the first.

When the mixture of gas and liquid rises in a channel with a uniform cross-section the ratio of the mixture will change more and more to the advantage of the gas. It is quite conceivable, therefore, that at the bottom of such a channel the ratio of the mixture may be such that the foam condition may exist, while at a certain height, in consequence of the decrease in pressure, there would be too much gas present in proportion to the liquid, so that the foam condition would have to give way to a mist condition.

Should this occur, however, a much greater difference in velocity would suddenly arise at the height in question and in consequence of this the ratio of the mixture would again change to the advantage of the liquid, so that there would be too much liquid present in the mixture for the mist condition. The mist condition cannot, therefore, arise immediately. This is only possible higher up after the pressure has decreased still more and the ratio of the flow, the absolute velocity and also the ratio of the mixture have changed much more to the advantage of the gas. Therefore there will be a zone where neither the foam condition nor the mist condition is possible. Should the foam condition arise for a moment in this zone, the accompanying small difference in velocity would cause too much gas to be present in the mixture and the mist condition would have to arise. Similarly, if the mist condition then arose for a moment the liquid would again predominate in the mixture in consequence of the large difference in velocity and the foam condition would again arise, which, however, as has been described, would have to give way again to the mist condition. There is a vicious circle here.

The result will be that a part of the gas will rise with as much liquid as it can entrain in the mist condition. The remaining liquid will keep as much gas confined as it is possible for it to contain in the foam con-

dition. At first, therefore, larger foam bodies will be entrained in the mist. These will have a tendency partly to remain behind, that is to say, to rise more slowly, and yet at the same time to give off continually more mist. Differentiation, therefore, takes place and in consequence there is periodical flowing. This differentiation more or less conforms with the differentiation described heretofore, which may be caused without difference of velocity in case the fields of foam and mist conditions do not meet.

The larger bodies of foam entrained by the gas, or the mist, when segregation takes place, will have a greater difference of velocity with the surrounding gas than the small drops in mist condition. In many cases even the difference of velocity would be greater than the velocity of the gas and the larger bodies would not be lifted. In this event they are thrown up from time to time, and this can cause real intermittence.

The question of the intermediate condition between the foam condition and the mist condition, due to difference in velocity, can be summarized as follows. The great difference in velocity existing in the mist condition causes a lower ratio of gas to liquid. In consequence of this, if the ratio of the flow of gas and liquid is not very high, the ratio of mixture will arise at which the foam condition must result. As soon, however, as this arises the difference in velocity becomes small and the ratio of mixture of gas to liquid becomes high again, so that the foam condition becomes at once impossible.

According as the absolute velocity is greater, the influence of the difference in velocity on the ratio of the mixture is smaller. As the difference in velocity always transposes the ratio of the mixture towards that of the foam condition, a great velocity of rise, which itself is promoted by a small cross-section, will in general have a tendency to make the ratio of the mixture favorable for the mist condition.

With certain quantities of gas and liquid flowing through per unit of time, two critical cross-sections exist, for the foam condition is possible only up to a certain maximum velocity, thus to a certain minimum diameter. The foam condition exists, therefore, only when the cross-sections are larger than the larger of the two critical ones, and the mist condition only when the cross-section is smaller than the smaller critical one.

It must, however, be borne in mind that the mist condition is not possible with every ratio of flow. This condition is not tenable when more liquid flows through than gas. The difference in velocity can never make the ratio of mixture more favorable to the gas than the ratio of flow. The foam condition can take place theoretically with every ratio of flow if the cross-section is large enough. An extreme case would be when the quantity of liquid rising is 0.

Every pipe in which a mixture of gas and liquid rises will show a certain intermittency in flow when in one part the cross-section lies between

the two critical ones for the ratio of flow prevailing there (which, as said, depends primarily on the pressure).

Mathematically the principle can be deduced simply as follows:

As has already been said, no matter which prevails, the foam condition or the mist condition, there is a difference in velocity between gas and liquid, which will be represented by b.

If the velocity of the gas is u, that of the liquid is $u - b$. If per unit of volume of liquid at the prevailing pressure, n volume units of gas flow through at a pressure prevailing in a certain cross-section, then in that cross-section, for each unit of volume flowing through per unit of time, a surface of:

$$\frac{1}{u-b} \text{ is occupied by liquid} \tag{1}$$

and

$$\frac{n}{u} \text{ by gas} \tag{2}$$

If the cross-section per unit of volume liquid flowing through per unit of time is S, then

$$S = \frac{n}{u} + \frac{1}{u-b} \tag{3}$$

It follows from equations 1 and 2 that although gas and liquid flow through in the ratio n, they are mixed in the cross-section in the ratio

$$\varphi = \frac{n}{u} : \frac{1}{u-b} = \frac{n(u-b)}{u} \tag{4}$$

As always

$$\frac{u-b}{u} < 1$$

consequently

$$\varphi < n \tag{5}$$

That is, the ratio of the mixture is higher than the ratio of the flow.

If then, the velocity is taken from equations 3 and 5, S may be expressed as follows:

$$S = \frac{(n-\varphi)(\varphi+1)}{\varphi b} \tag{6}$$

It is known from observation that in the foam condition $b = 8$ to 12 in. and in the mist condition 250 to 300 in. per second.

In order to be on the safe side (that is, not to take the limits of the intermittency too narrow) it is taken here that

for the foam condition $\quad b = 8$ in. per sec. (7a)
for the mist condition $\quad b = 400$ in. per sec. (7b)

If the foam condition exists and the volume of the bubbles increases in proportion to that of the liquid, it may be assumed that if there is no stabilizer present (in water this may be soap, for instance) the bubbles will touch one another and flow together when the gas volume is as

large approximately as the liquid volume. This means that the liquid disperses in drops.

In the same way, when the mist condition exists, the drops will touch one another and have a tendency to unite when their total volume becomes as large as that of the gas. A continuous liquid mass then forms which contains gas bubbles. Although it is not quite correct to do so, for the sake of simplicity it will be taken that $\varphi = 1$ is the limit of the possibility of the existence of either the mist condition or the foam condition.

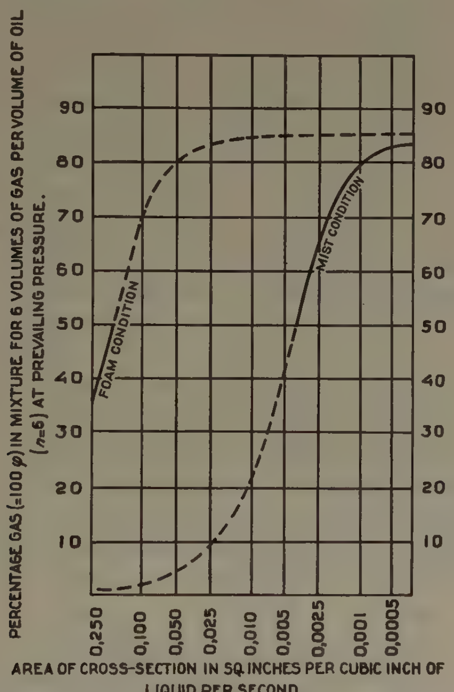

FIG. 1.—FOAM AND MIST CONDITIONS FOR VARIOUS PERCENTAGES OF GAS IN MIXTURE.

If $\varphi > 1$, the mist condition prevails, while if $\varphi < 1$, the foam condition prevails. This applies to water and to many grades of oil. It may be thought that φ may be greater for some kinds of oil. Provisionally, however, φ is taken as equalling 1.

Further, the fact that the difference b becomes smaller both in the foam condition and in the mist condition if the volumes of gas and liquid in the mixture become approximately equally large will be left out of consideration.

The value in equation 7*a* is probably approximately exact, the value in 7*b* is too great. By assuming the latter value, which is exaggerated, the limits of the range of diameter of a tubing to be avoided, on account of the irregular flow that would be caused, if calculated according to the

deductions will spread farther than they really do. So we are safe in assuming the values of 7*a* and 7*b*.

As an example, in Fig. 1 there are plotted in semilogarithmic coordinates the percentages of gas in the mixture against the values of S for $n = 6$. In this diagram the values of S are expressed in square inches per cubic inch of liquid flowing through per second (when we come to practical applications, we will substitute barrels per day). The values of S have been computed by the aid of equation 6, in which have been substituted the values of φ corresponding to the different percentages of gas in the mixture. On account of the existence of two values of b, see equations 7*a* and 7*b*, two lines can be traced.

If we assume that foam condition in a mixture is able to exist as long as less than 50 per cent. gas is present, and that with more gas the mist condition would arise, which is probably not strictly the case, then only the traced parts of the two lines would be available, the broken parts not corresponding to real conditions. Then, although generally speaking with 50 per cent. gas in the mixture there would be a transition from foam into mist, in the particular case of the mixture rising in a tubing no direct transition from foam to mist can be established by gradually decreasing the section.

Within the range of values of S between the limits 0.2 and 0.04 none of the conditions will exist. These figures, read from Fig. 1, are available only if $n = 6$, but for any arbitrary value of n, a similar diagram can be drawn and a range of values of S will be found which do not allow the mixture to rise either under foam or under mist condition. Within the range of these values of S the mixture is not able to flow regularly. As in a mixture the mist condition probably arises only if the gas content is more than 50 per cent., and foam condition is limited by a little less than 50 per cent. gas, the limits will be farther apart than would appear from the diagram. Inaccuracies on account of this, however, are more than counterbalanced by the too great value chosen for b (equations 7*b*).

By taking $\varphi = 1$ in equation 6, the value of S is obtained for the transition state from foam to mist:

$$S_l = 2\frac{n - 1}{b} \qquad [9]$$

When the transition state is reached from the foam condition, $b = 8$ and

$$S_{lf} = \frac{n - 1}{4} \qquad [10]$$

and when reached from the mist condition, $b = 400$ and

$$S_{lm} = \frac{n - 1}{200} \qquad [11]$$

As already concluded by reasoning, there are, therefore, two critical cross-sections, which are expressed per unit of volume of liquid for a certain ratio of flow n by equations 10 and 11. It follows that:

$$S_{lf} = 50 S_{lm} \tag{12}$$

In order to make the mist condition at once possible, when rising takes place, where the foam condition is no longer possible, the cross-section of a pipe would have to be 50 times as small and the diameter $\sqrt{50}$, or about seven times as small.

In Fig. 2 the lines representing equations 12 and 13 are traced, the limits S_{lf} and S_{lm} being computed in square inches per barrel of liquid per day. In this diagram logarithmic coordinates are used; had the values of S_l and n been plotted directly, straight lines would have been obtained. This diagram shows that only large quantities of gas or narrow tubes are favorable to the existence of mist condition.

In oil wells generally the tubing or the oil string through which the well produces has a uniform cross-section from the bottom to the surface, though there may be one or two sudden enlargements, so that the magnitude S in the above formulas remains constant for a certain length. But as the mixture rises the pressure decreases and accordingly the volume of gas (n in the formulas) increases. The value of n in the formulas is the gas-oil ratio at the prevailing pressure. Hence it is the gas-oil ratio at atmospheric pressure divided by the prevailing pressure for every cross-section, if the solubility of the gas in the oil is neglected. This however may not be done, with small gas-oil ratios. If the gas-oil ratio at atmospheric pressure be denoted by N, then in neglecting the solubility we would write:

$$n = \frac{N}{p} \tag{13}$$

if p denotes the prevailing pressure for the cross-section of the flowing pipe under consideration in atmospheres.

If we take the solubility into regard, we must write:

$$n = \frac{N}{p} - \alpha \tag{14}$$

if α is the absorption coefficient, which approximately equals 2.5 cu. ft. per barrel.

If p is expressed in pounds per square inch, equation 14 should be written as follows:

$$n = 14.7\frac{N}{p} - \alpha \tag{14a}$$

For each production and each ratio of gas and oil at the prevailing pressure, the diameter of the pipe must be narrower than the smallest diameter indicated in the nomogram or wider than the largest of the

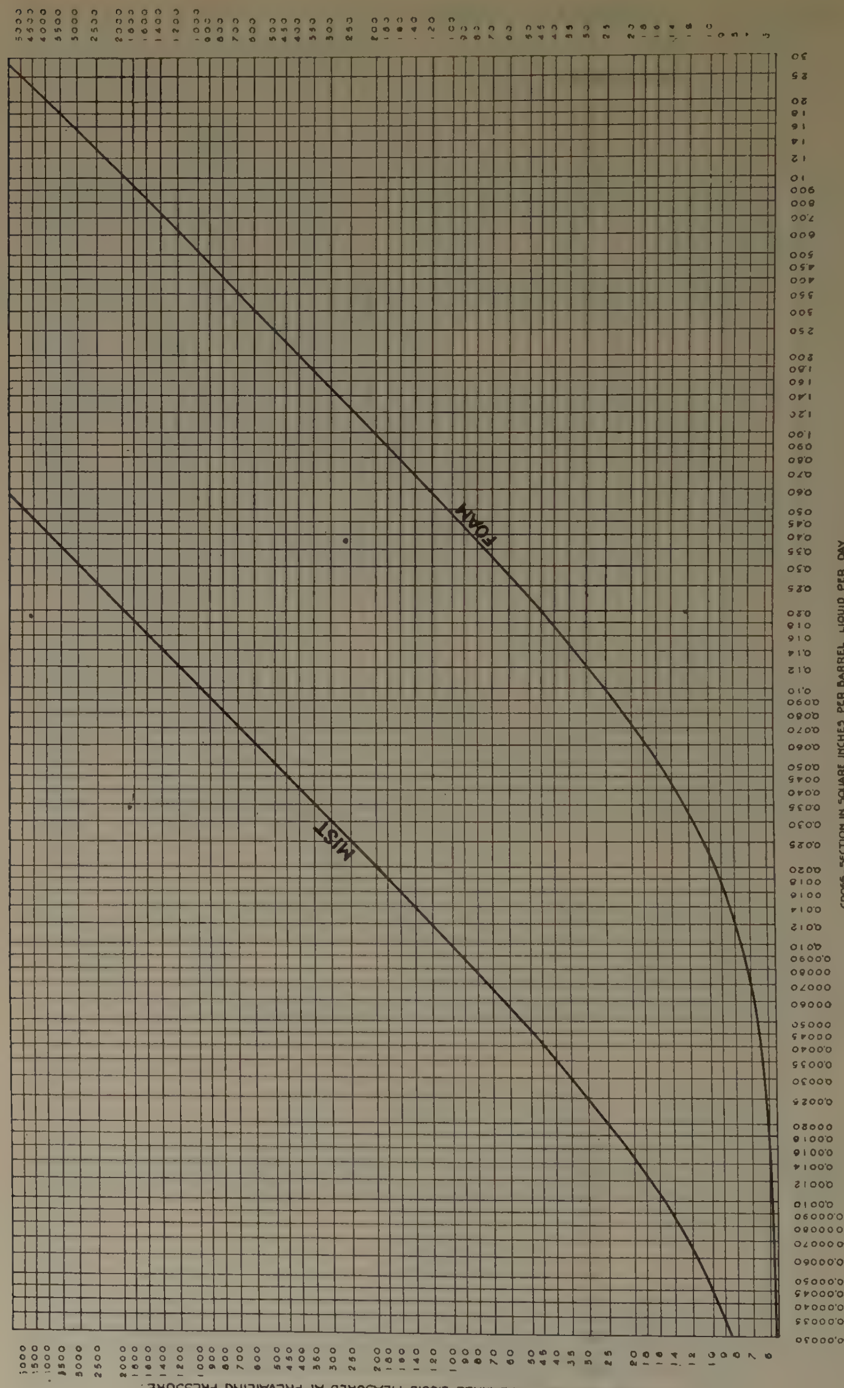

FIG. 2.—LIMITS OF MIST AND FOAM CONDITIONS IN TUBING OR CASING.

diameters so indicated. If the diameter of the pipe lies between these critical diameters, the well flows irregularly.

The gas-oil ratio referred to in Fig. 3 varies with the pressure and this ratio for each cross-section of the well is known only if the pressure there is known. It will first be assumed that this is known everywhere. Care must be taken that the well flows at any height through a pipe, either the casing or the tubing, of which the diameter lies outside the two critical ones. If the casing is wider than the larger critical diameter for the gas-oil ratio at the pressure prevailing at the bottom of the well, the tubing need not reach to the oil-bearing layer. With the chart of Fig. 3 it can then be calculated for the given oil production and the diameter of the casing at the pressure at which the casing is no longer sufficiently wide for the foam condition. If, as is now considered to be the case, the pressure at every height is known, it is also known, in view of the foregoing, what the least height is to which the tubing must reach; for instance, by means of Fig. 3 for the diameter of the oil string and the oil production may be read the gas oil ratio n at prevailing pressure. Substituting this in formula 14, which is directly deduced from formula 13 and the gas-oil ratio at atmospheric pressure for N, the formula gives the value of p at which the oil string becomes too narrow for a regular flow in the foam condition:

$$p = \frac{N}{n}\text{ atmospheres or:} \qquad [15]$$

$$p = 14.7\frac{N}{n}\text{ lb.} \qquad [15a]$$

The oil production and the gas-oil ratio at the pressure prevailing at the bottom of the tubing are known and the tubing is not made wider than the smaller of the respective critical diameters. It is then certain that the well will flow regularly. It is possible that the pressure or the quantity of gas present is not sufficient to lift the oil. This point will be put aside for the present.

If, as has been assumed, the pressure at every height is known, it would be possible, at least theoretically, to allow the diameter to increase gradually upwards, so that at each height this corresponds to the smaller critical diameter for the pressure prevailing there. This however would not be the best method. Better to make the pipe narrower over the entire length, as the critical diameter is fixed in such a way that the velocity of the liquid is extremely small. The loss of energy through slippage is proportional to the time required by each liquid particle to rise in the well.[5] This loss of energy may be very great in the mist condition. In order to reduce this loss the tubing must be considerably narrower in general than the smaller critical diameter, for if the tubing is narrower,

[5] J. Versluys: *Op. cit.*, formula 21.

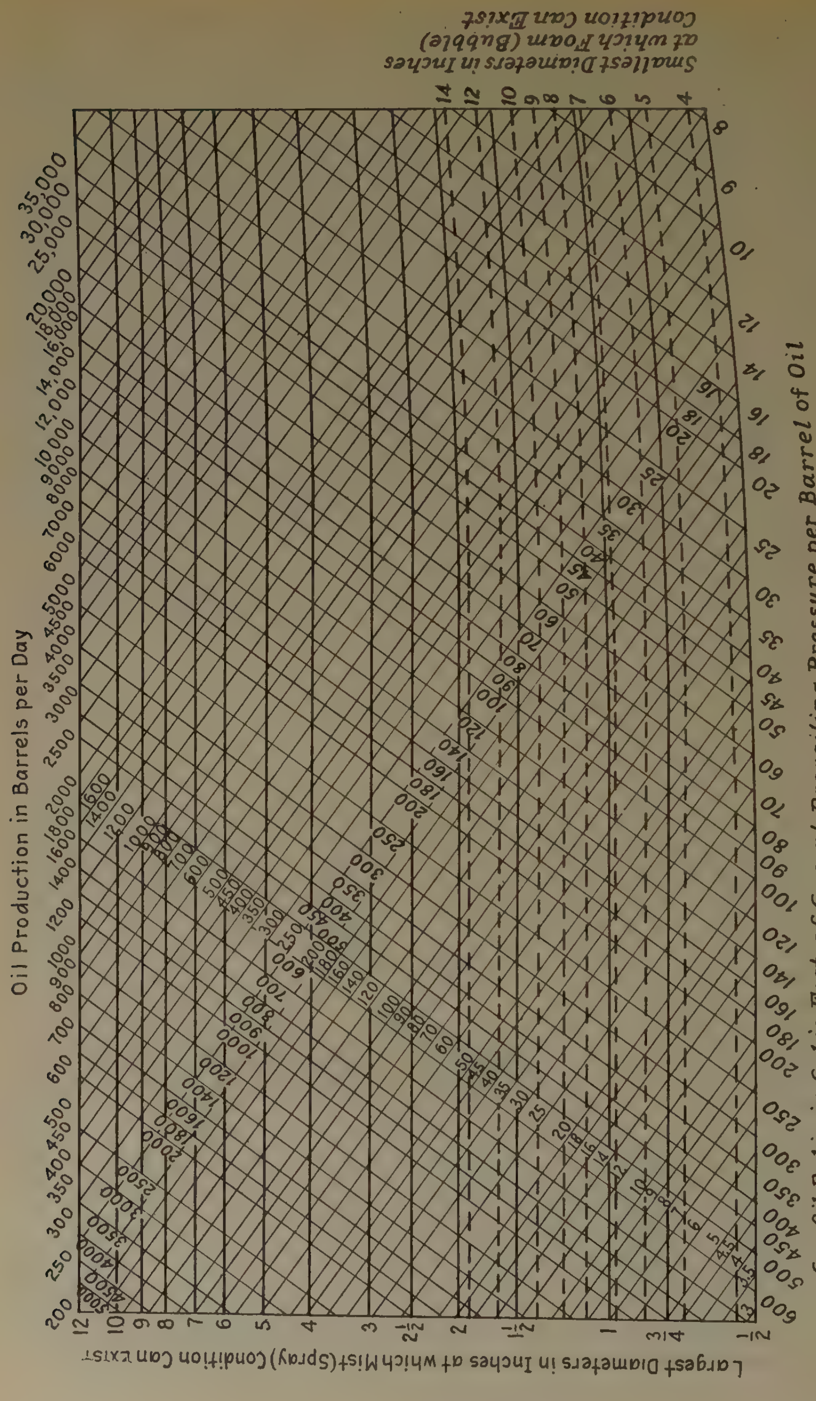
Smallest Diameters in Inches at which Foam (Bubble) Condition Can Exist
Oil Production in Barrels per Day
Gas-Oil Ratio in Cubic Feet of Gas at Prevailing Pressure per Barrel of Oil
Largest Diameters in Inches at which Mist (Spray) Condition Can Exist

FIG. 3.

the velocity of rise is greater and the time required by the particle to travel through the pipe is the smallest. On the other hand, the velocity of the mixture of gas and oil may not be allowed to be very great, as too much potential energy is then converted into kinetic energy[6] and also because the turbulence resistance[7] would become too great.

The turbulence resistance is the least known of all losses of energy in the gas-lift[8] but often too much importance is attached to this. If this were of paramount importance, the wells should always flow best without tubing, while as a matter of fact the substituting of tubing for the much wider casing for lift pipe is the result of practical experience.

The diameter of the tubing, as has already been concluded above, must be either equal to or smaller than the smaller critical diameter at each height, in order to obtain a regular flow, but this must also be, in general, as small as possible in order to reduce the slippage loss. As has already been pointed out, however, the diameter must not be too small, in order to prevent too much potential energy from being converted into kinetic energy or being exhausted by turbulence resistance. Too great a velocity must in any case be avoided. The velocity determines the kinetic energy, but also the loss of energy through turbulence resistance.

With respect to the loss of energy due to turbulence resistance, reference could be made to W. G. Heltzel's paper.[9] In the mist condition the drops of oil are disseminated in gas and for the viscosity, the square root of which enters the resistance formula, a figure sometimes greater than viscosity of gas would have to be substituted. Further, the specific gravity of the mixture, with which the turbulence resistance is proportional, is many times less than for oil or water.

We must conclude that as the diameter becomes smaller for certain amounts of oil and gas flowing through in the mist condition, turbulence resistance increases, but not to such a degree as one is inclined to assume. From these considerations it may be concluded that a certain velocity of the rising mixture is favorable.

As the gas expands during its rise at the bottom of the well the tubing must not be smaller than is necessary to ensure a good working; *i. e.*, not smaller than computed by the aid of the chart. Although the loss due to slippage may then be great in the lower part of the tubing, it will promote the most favorable condition higher in the tubing. If the velocity in the upper part of the casing should become very great, on account of the expansion of the gas, a tapered tubing can be used.

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[6] J. Versluys: *Op. cit.*, formulas 9 and 48.

[7] J. Versluys: *Op. cit.*, formulas 11 and 50.

[8] J. Versluys: *Op. cit.*

[9] W. G. Heltzel: Fluid Flow and Friction in Pipe Lines. *Oil & Gas Jnl.* (Oct. 7, 1926) C158–C171.

As far as the author knows, there are no data available concerning the resistance of a sudden enlargement of a pipe to the flow of a mixture of oil and gas. If we assume, however, that the law of the resistance of a sudden enlargement with a single liquid or gas applies to the mixture, then it follows[10] that such enlargements do not cause a considerable resistance if the density of the mixture is substituted.

The fact that the velocity of a liquid or a gas flowing through a tubing in the center of the cross-section is greater than near the wall has not been appreciated. Probably this causes a small deviation, but errors on account of this will be counterbalanced by the exaggerated value chosen for the difference of speed $b = 400$ inches

Probably the limits of the range of diameters causing intermittent flow are not sharp. If the value of the diameter is near the middle of the range of intermittent flow, the tubing will alternately eject oil occluding little gas and gas containing a small percentage of oil in drops. The nearer the diameter approaches one of the limits, the shorter the period of intermittence will become and at last, but still before the critical diameters have been reached, one can speak of a regular flow, though the oil forms large, irregularly shaped bodies. Under these conditions, we may assume that the efficiency will be very small because the mixture of gas and oil is not intimate, owing to the fact that the difference of velocity b will be greater even than 400 in., as has been explained. Wells that are not tubed according to these principles often cause trouble. It is difficult to bring them into production and the flow may cease suddenly.

By means of Fig. 3, if the tubing is too wide to allow a regular flow for the amounts of oil and gas flowing through, the quantity of gas that must be injected to establish a regular flow can be computed.

DISCUSSION

(*W. W. Scott presiding*)

T. V. Moore,* Houston, Tex.—Dr. Versluys has brought out some very interesting ideas but many who have conducted experiments along these lines have failed to attach the proper importance to these points, and therefore, their data are difficult to interpret. In an experimental study of the flow of gas-oil mixtures in vertical pipes, sufficient data must be taken to segregate the total pressure drop into its component parts: hydrostatic head, velocity head and friction loss. Dr. Versluys emphasizes the importance of relative velocity. If data on the relative velocity of gas past the oil are taken, the data may be analyzed and correlated in a rational manner. Any who may carry on these experiments in the future can enhance the value of their data by following this procedure.

However, there are one or two points on which I would like to take issue with Dr. Versluys. He claims that the type of flow that is intermediate between the true mist and true foam type is unsteady and inefficient. I doubt whether sufficient data are

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[10] H. W. King: Handbook of Hydraulics, Ed. 1, 181. New York, 1918. McGraw-Hill Book Co.

* Humble Oil & Refining Co.

available to warrant this definite conclusion but even if this type of flow should be proved to be unsteady, I believe that the data already available are sufficient to show that this type of flow is not inefficient. Generally, if a flow string were designed to handle oil and gas at the rates and pressures normally encountered in many flowing wells under the mist conditions, the flow string would be so small that there would be excessive friction loss. If the tubing were made large enough to cause the true foam type of flow to prevail, the slippage losses would be so great as to make the string very inefficient. The ideal flow string is one that so balances the friction losses and slippage losses as to carry a given amount of oil and gas with the minimum pressure drop. I believe that generally this type of flow string will cause the intermediate type of flow to prevail and in order to obtain the minimum pressure drop, it would probably be well to suffer whatever disadvantages there might be to a type of flow which might be unsteady.

The impression that I have obtained from Dr. Versluy's paper is that he believes that heading wells are caused by the use of improperly designed tubing. The problem of a heading well is deeper than the flow string. That efficient flow strings cannot in all cases stop the heading of wells is shown by the fact that in some fields several wells may be equipped with the same tubing, having the same bottom-hole pressures and comparable production rates, and yet some will head while others will flow steadily. In many cases, heading is undoubtedly due to a combination of excessive energy losses both in the sand and in the flow string and in some cases to the pressure losses in the sand alone. No satisfactory theory has been advanced to explain the phenomenon of heading wells in all cases. It is very doubtful whether the heading of a high-pressure well is dependent to any great degree on the type of flow string used. However, I believe that the heading of wells often can be explained by the fact that when the rate of oil production increases the bottom-hole pressure falls off markedly until it falls to such a low value that the well will cease to flow. The flow having stopped, the pressure losses due to friction in the sand are eliminated. The bottom-hole pressure may then build up to so high a value that the well is kicked off and flow is resumed. Thus, the excessive pressure losses in both the sand and the flow string cause this cycle of flow and cessation of flow, which is commonly called heading, to occur. I believe that in many instances heading wells can be made to flow steadily by the use of a more efficient flow string, but the exact design of the efficient string is still an open question.

We have collected considerable data on the flow of gas and oil mixtures in vertical pipes, and all of our data, as well as data of many other investigators, seem to indicate that the greater the amount of gas flowing past the oil, the larger the pipe diameter required for maximum efficiency. Thus the ideal flow string should be one tapered gradually from the bottom to the top, and not one with a large cross-sectional area at the bottom which is decreased suddenly to a very small area at some point about halfway up the pipe. I do not believe that in wells with high bottom-hole pressures a flow string that will give maximum mechanical efficiency is necessary. The benefits of tubing in such wells can be obtained with some simple standard string of tubing as well as by a specially designed string. Therefore operators should study the problem of tubing their wells thoroughly, and should maximum mechanical efficiency be necessary a flow string tapered regularly from top to bottom should be given careful consideration.

J. Versluys (written discussion).—There must be some misunderstanding in Mr. Moore's discussion. I never recommended tubings which should be wide at the bottom and narrow at the top with a sudden transition from one diameter to the other. My principle is using tapered tubings, which are narrow at the bottom and wider at the top. In many cases, however, a tubing of uniform cross-section throughout will do.

When I speak of sudden enlargements (p. 292), I simply mean to avoid the objections of some engineers who believe that sudden enlargements should be rejected because they cause much resistance, but I do not mean that tubings should be narrower at the top than at the bottom. On page 291 it is stated that slippage loss becomes smallest when diameter is minimum but that an excessively narrow bottom end of the tubing offers too much turbulence resistance. Therefore in cases where the volumes of oil and gas (under the prevailing pressure) flowing through are so small at the bottom of the well that the bottom part of the tubing should be designed very narrow in order to insure a flow in mist condition, this narrow part of the tubing often can better be omitted, which means that then a shorter tubing is preferable. In the lower part of the well the mixture of gas and liquid then may rise in the casing if this is actually or almost wide enough to permit the existence of the foam condition. Where I advocated a wider diameter for the flow in the lower part of the well, I simply meant a shorter tubing, and it seems that here I have been misunderstood by Mr. Moore.

I said that the flow in the intermediate condition was unsteady and inefficient. The former is true, although it is not always recognized. In all cases where wells with unsteady flow were changed according to my principles, the flow became steady. So it seems to me that the principle which was deduced theoretically has proved to be exact. The value substituted for b in the mist condition was taken on the safe side, so that diameters may be a little wider than my chart indicates, and moreover, in the intermediate field near the border of the field of mist condition, not such a fierce heading will arise that this would do much damage. On the other hand, however, as production of wells gradually declines, it is better to have tubings that are narrow at the beginning, so that they may meet the requirements of flow for a longer period. The paper was written in the beginning of 1929. Since then I have realized, as Mr. Moore contends, that flow in the intermediate condition is not always inefficient. When writing in my article that unsteady flow is inefficient, I had in mind principally wells really flowing by heads; that is to say, which produce oil by jerks. In such wells part of the gas flows out without lifting any oil and the flow must be inefficient. If there is only a fluctuation with a short period the flow need not be inefficient.

In computing the charts for my paper, I substituted an exaggerated value for the relative velocity b in order to be "safe." Consequently the diameter may be wider than would follow from the charts and still permit flow in mist condition. Moreover, in this paper and in the earlier one,[11] I have mentioned several factors on which the value of the relative velocity b depends. During the last six months I have concluded that the value of the mixing proportion φ is probably the most important factor. That is to say, when the gas bubbles approach one another, the value of b decreases in the foam condition, while the same is true when the drops are closer together in the mist condition.

Another question, not yet discussed, is that perhaps the wall of the tubing is lined with liquid and such liquid must have a downward motion. If this principle holds good, the average difference of velocity is increased on account of it.

In order to prove that the intermediate unstable condition often occurs without being recognized, I may refer to a paper by Mr. Moore and Mr. Wilde,[12] in which it is remarked that the manometers showed pulsation during the runs of their experiments.

When studying the descriptions of air-lift experiments[13] performed with glass tubes, it appears that even when gas and water are well mixed at the bottom, they segregate if intermediate condition prevails. Very large bubbles of air, nearly as

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[11] Mathematical Development of the Theory of Flowing Oil Wells. *Trans.* A. I. M. E., Petr. Dev. and Tech. (1930) 192.

[12] See page 296.

[13] K. Höfer: Forschung., Ver. Deut. Ing. (1913) **138**.

wide as the tube, are formed, through which, however, water falls down in the shape of drops, while smaller bubbles rise in the water columns between the bigger air bubbles. The intermediate condition probably must be conceived like this. The mixture segregates into bodies of mist and foam. The intermediate condition often prevails only in a part of the tubing, and when it is in the lower parts, the bodies of foam, on account of further expansion of the confined gas, are gradually dissolved in the mist when rising further in the part of the tubing where conditions are favorable for mist. In these circumstances only a slight vibration of the manometer can be discerned and when the well flows out into the air, the spray alternately becomes more and less dark. As a rule the period of this fluctuation is very short. How far fluctuations due to unstable condition are shown by a manometer connected to the tubing head partly depends on the length of tubing above the part in which conditions are unstable and fluctuations are created.

The unstable condition which is a consequence of the intermediate condition causes a so-called relaxation fluctuation, as was explained in my paper and in other papers I have published on the same subject. The cause of fluctuation and unstableness was explained as follows. When in the unstable field foam condition occurs, the small value of b causes an increase of the proportion of liquid to gas which is unfavorable for the existence of this very condition. This would create the mist condition, which, however, brings about a greater value of b and as a consequence a decrease of the proportion of liquid to gas. This, however, destroys the mist condition. Fluctuations, due to such a phenomenon, are relaxation fluctuations. Relaxation fluctuations or vibrations may also arise when there is friction of solid bodies; for instance, when a train is stopped by using the brake. Then however, many phenomena interfere, which are entirely different from the internal friction of fluids, which interfere with flowing oil wells. I do not believe that such vibrations can be caused by "a combination of excessive energy losses both in the sand and in the flow strings," as Mr. Moore suggests. It should not be lost sight of that fluids have no elasticity and that in fluids resistance approaches zero, according as the relative motions are reduced to zero. Therefore I doubt whether Mr. Moore's suggestion that excessive friction in liquid and gas could cause a vibration is well grounded.[14] Despite Mr. Moore's opinion, I believe that unsteady and unstable flow in wells is due to the variation of relative velocity of liquid and gas.

The unstable flow, which often occurs without being recognized, should, as Mr. Moore states, not be avoided for sake of efficiency. It may, however, disturb sand conditions and the wells are more apt to stop flowing and more difficult to get started when flow conditions are unstable. As long as wells are beaned, so that part of the energy is destroyed deliberately, there is certainly no reason to bother about the efficiency.

Mr. Moore writes: "That efficient flow strings cannot in all cases stop the heading of wells is shown by the fact that in some fields several wells may be equipped with the same tubing, having the same bottom-hole pressures and *comparable* production rates, and yet some of these will head while other will flow steadily." What does "comparable" mean? In the first place, conditions should be the same—not only comparable—to prove anything. Moreover, how is bottom-hole pressure ascertained when the well heads? I believe that Mr. Moore could just as well have concluded that in the fields referred to production of most of the wells has so far declined that either they should be helped by extraneous gas or should be equipped with narrower tubings.

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[14] A good description of relaxation vibrations is given in French by B. Van Der Pol in *L'onde électrique* (July 9, 1930) 293–312.

Experimental Measurement of Slippage in Flow through Vertical Pipes

By T. V. Moore* and H. D. Wilde, Jr.,* Houston, Texas

(New York Meeting, February, 1931)

In many of the important problems of the petroleum engineer, it is necessary to know accurately the laws governing the flow of gas and liquid mixtures in vertical pipes. Although much work has been done along these lines, no satisfactory solution to the problem has been found. A good theoretical discussion of the energy balance in a gas-lift has been published by Versluys.[1] One of the most important factors affecting the efficiency of the flow of oil and gas mixtures is slippage, and in most of the experimental work that has been done no provision has been made for the measurement of this quantity. As Versluys pointed out, since there is no method now known to estimate it from the data usually taken, slippage must be determined empirically.

This paper presents the results of some work carried on to measure slippage in short experimental gas-lifts. As shown herein, slippage can be easily calculated in a vertical pipe carrying a mixture of oil and gas if the fractions of the pipe occupied by liquid and gas respectively are known. In this work, the fraction of the pipe occupied by the liquid was measured under a wide variety of conditions and the relationship between this fraction and other quantities, which are easily measured in ordinary work, was determined.

It was hoped that the quantitative relationship obtained from this work could be used for making accurate calculations in flowing or gas-lift wells, but unfortunately it did not check satisfactorily when applied to actual wells. Apparently flow in long flow pipes is more efficient than in the short ones used for the experimental work. Nevertheless, it is felt that the data themselves are of interest; that the method of attack may be of value in future work and that the relationship derived between slip and the relative velocities is a contribution toward the solution of the gas-lift problem.

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* Production Research Department, Humble Oil & Refining Co.

[1] J. Versluys: Mathematical Development of the Theory of Flowing Oil Wells. *Trans.* A. I. M. E., Pet. Dev. and Tech. (1930) 192.

Nomenclature

Throughout this paper, the following nomenclature has been employed:

Symbol	Definition	Units
H	Length of pipe	Feet
S	Submergence	Feet
d	Pipe diameter	Feet
D	Pipe diameter	Inches
A	Cross-sectional area of pipe	Square feet
L	Rate of liquid flow	Cubic feet per minute
G	Rate of gas flow through pipe	Cubic feet per minute at standard pressure
G'	Rate of gas flow through pipe	Cubic feet per minute corrected to average pipe pressure
ρ_L	Density of liquid	Pounds per cubic foot
ρ_G	Density of gas	Pounds per cubic foot
s	Specific gravity of liquid	Relative to water at 60° F.
z	Viscosity of liquid	Centipoises
γ	Surface tension of liquid	Dynes per centimeter
u_L	Linear velocity of liquid	Feet per second
u_G	Linear velocity of gas	Feet per second
u_R	Relative linear velocity	Feet per second
V'	Relative volume velocity	Cubic feet per minute
y	Fraction of pipe occupied by liquid	No units
x	Ratio of fraction of pipe occupied by liquid to that occupied by gas	No units
P_B	Pressure at bottom of pipe	Pounds per square inch absolute
P_T	Pressure at top of pipe	Pounds per square inch absolute
P_{av}	Average pressure in pipe	Pounds per square inch absolute
P_{at}	Atmospheric pressure	Pounds per square inch absolute
ΔP	Total pressure drop	Pounds per square inch
ΔP_L	Pressure drop due to hydrostatic head of liquid	Pounds per square inch
ΔP_u	Pressure drop due to velocity head of liquid	Pounds per square inch
ΔP_F	Pressure drop due to friction	Pounds per square inch
k	Henry's law constant	Cubic feet gas dissolved per cubic foot liquid per pound per square inch
g	Gravitational constant	Feet per second per second

Relationship of Quantities

If G cu. ft. of gas and L cu. ft. of liquid per minute flow through a pipe wherein the average pressure is P_{av}, the gas dissolved in the liquid

is $kP_{av}L$. The undissolved gas is, therefore, $G - kP_{av}L$ cu. ft. measured at atmospheric pressure. Correcting for pipe pressure, we have:

$$G' = \frac{P_{at}}{P_{av}}(G - kP_{av}L) = \frac{GP_{at}}{P_{av}} - kP_{at}L \tag{1}$$

In a pipe carrying liquid and gas, the average fraction of the pipe that is filled with liquid is designated as y, the average area through which the liquid flows is Ay, and that through which the gas flows is $A(1 - y)$. Hence, if L cu. ft. of liquid per minute are flowing, we have for its linear velocity:

$$60u_L = \frac{L}{Ay} \tag{2}$$

The factor of 60 corrects the linear velocity from feet per minute to feet per second.

Similarly,
$$60u_G = \frac{G'}{A(1 - y)} \tag{3}$$

The relative linear velocity of the gas with respect to the liquid is, obviously,

$$u_R = u_G - u_L \tag{4}$$

The relative volume velocity, or cubic feet of gas per minute flowing past the liquid, is the relative velocity multiplied by the cross-sectional area through which the gas flows:

$$\begin{aligned} V' &= 60u_RA(1 - y) \\ &= 60(u_G - u_L)(A)(1 - y) \end{aligned}$$

Substituting equations 2 and 3,

$$\begin{aligned} V' &= \left(\frac{G'}{A(1 - y)} - \frac{L}{Ay}\right)(A)(1 - y) \\ &= G' - L\frac{(1 - y)}{y} \end{aligned}$$

But
$$\frac{y}{(1 - y)} = x \text{ (by definition)}$$

Therefore,
$$V' = G' - \frac{L}{x} \tag{5}$$

These equations give the fundamental relationships between the various quantities, and are derived largely from the definitions of the quantities themselves and not from theoretical relation between the quantities.

Generally, the problems connected with the air-lift may be solved either by calculating the various components of the pressure drop or by making an energy balance. The total pressure drop is equal to the sum of its components:

$$P_B - P_T = \Delta P = \Delta P_L + \Delta P_F + \Delta P_u + \text{velocity head of gas} + \text{hydrostatic head of gas.} \tag{6}$$

In the calculation of components of the pressure drop, the hydrostatic head of the liquid and friction loss are the only important ones. Velocity head of the liquid is given by the expression:

$$\Delta P_u = \frac{(u_L)^2 y}{2g} \qquad [7]$$

However, this factor is unimportant under the conditions usually encountered in actual practice and can be neglected. The velocity head of the gas is usually of even less importance.

If we consider a section of pipe carrying liquid and gas of length dH, the weight of liquid in the pipe is:

$$\text{Weight of liquid} = (yAdH)(\rho_L)$$

This weight is exerted over an area A. Therefore the pressure drop due to the hydrostatic head of this liquid is:

$$dP_L = y\rho_L dH$$

As y does not remain constant throughout the length of the pipe, in the case of long sections, this expression must be integrated:

$$\Delta P_L = \rho_L \int y dH$$

However, for fairly short sections, the variation of y is relatively small and this equation may be approximated as:

$$\Delta P_L = y\rho_L H \qquad [8]$$

A similar expression can be developed for the hydrostatic head of gas, but usually this term can be neglected. Thus, if y is known, the hydrostatic head may be calculated easily. However, it is necessary that y be determined empirically unless its relation as a function of other variables which are more easily measured is known.

The factors controlling friction loss in the flow of heterogeneous fluids are not definitely known, but from what data are available the friction loss, ΔP_F, may be estimated approximately, and this added to hydrostatic head of the liquid will give, for all practical purposes, the total pressure drop:

$$P_B - P_T = \Delta P_L + \Delta P_F \qquad [6a]$$

The hydrostatic head ΔP_L is controlled by slip losses and gas-oil ratios. Slip loss is an energy loss, caused by gas rising in the flow string at a greater velocity than that of the oil being lifted. As a result of this, the ratio of liquid to gas contained in a given section of the pipe is greater than the ratio of liquid to gas flowing out of the section. Consequently, slip losses increase the hydrostatic head.

The following derivation shows how slip loss can be expressed as a fraction of the total energy given up by the gas in isothermal expansion. Fig. 1 shows a gas-lift in its simplest form.

Submergence is defined as the distance from the surface of the liquid in the reservoir to the bottom of the flow pipe when the pressure on the surface of the liquid in the reservoir is equal to that at the top of the flow pipe. Therefore

$$S = \frac{P_B - P_T}{\rho_L} \tag{9}$$

It is assumed that the density of the gas itself is negligible in comparison to that of the liquid, hence the average density of liquid-gas mixture within the flow pipe is $y\rho_L$. The velocity heads are also assumed to be negligible.

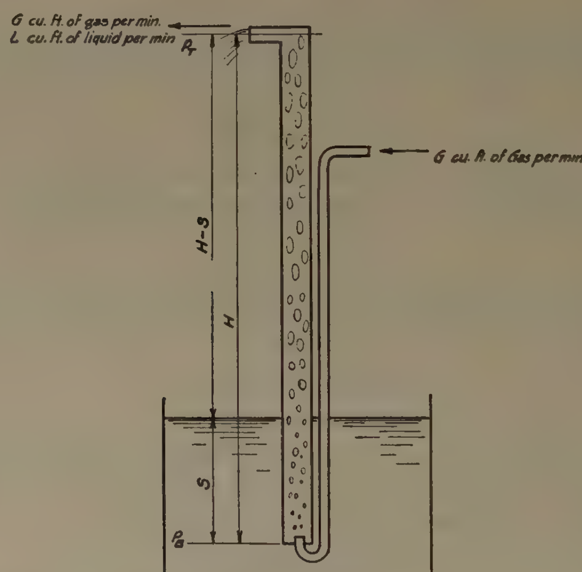

FIG. 1.—SIMPLEST FORM OF GAS-LIFT.

As shown in equation 6*a*, in most cases the friction drop in the flow pipe is the total pressure drop minus the hydrostatic pressure drop:

$$\Delta P_F = (P_B - P_T) - y\rho_L H$$

In order to express the friction in terms of head of the mixture flowing, this expression should be divided through by $y\rho_L$, which will give

$$\text{Friction head} = \frac{(P_B - P_T)}{y\rho_L} - H \tag{10}$$

The work consumed in friction is this head multiplied by the weight of fluid flowing against it. Neglecting the weight of the gas

$$\text{Friction loss} = L\rho_L\left(\frac{P_B - P_T}{y\rho_L} - H\right) \tag{10a}$$

The useful work done is the weight of liquid lifted multiplied by the effective lift; that is, the length of the flow pipe minus the submergence.

$$\text{Useful work} = L\rho_L(H - S) = L\rho_L\left(H - \frac{P_B - P_T}{\rho_L}\right) \qquad [11]$$

Adding these two items

$$\text{Useful work} + \text{friction} = L\rho_L\left(\frac{P_B - P_T}{y\rho_L} - H\right) + L\rho_L\left(H - \frac{P_B - P_T}{\rho_L}\right)$$

$$= L\rho_L\left[\frac{P_B - P_T}{\rho_L}\left(\frac{1}{y} - 1\right)\right] \qquad [12]$$

$$= L(P_B - P_T)\left(\frac{1 - y}{y}\right)$$

Under conditions usually encountered in gas-lifts and flowing wells, the temperature remains substantially constant and the gas expands isothermally. When a mixture of gas and liquid is flowing in a vertical pipe and the liquid is saturated at all times with the gas at the pressure on the mixture, the work of isothermal expansion as the mixture moves from the point at which the pressure is P_B to that at which it is P_T can be expressed as

$$\text{Isothermal work} = P_{at}G \ln \frac{P_B}{P_T} - kP_{at}L(P_B - P_T) \qquad [13]$$

This work is consumed in three ways: useful work, friction and slip loss. The fraction of the total energy of expansion of the gas consumed in useful work and friction is:

$$\text{Fraction} = \frac{L(P_B - P_T)\left(\frac{1 - y}{y}\right)}{P_{at}G \ln \frac{P_B}{P_T} - kP_{at}L(P_B - P_T)}$$

Dividing numerator and denominator by $P_B - P_T$

$$= \frac{L\left(\frac{1 - y}{y}\right)}{P_{at}G\frac{\ln P_B/P_T}{P_B - P_T} - kP_{at}L}$$

Since $\frac{P_B - P_T}{\ln P_B/P_T}$ is the logarithmic mean pressure, or P_{av},

$$= \frac{L\left(\frac{1 - y}{y}\right)}{\frac{P_{at}}{P_{av}}G - kP_{at}L}$$

From equation 1,

$$= \frac{L\left(\frac{1 - y}{y}\right)}{G'}$$

Dividing numerator and denominator by A and rearranging,

$$= \frac{\dfrac{L/Ay}{G'}}{A(1 - y)}$$

From equations 2 and 3,

$$= \frac{u_L}{u_G} \qquad [14]$$

Thus, the fraction of the total energy consumed in useful work and friction simplifies to u_L/u_G. The fraction of the total energy lost in slip is equal to one minus the fraction lost in useful work and friction, so

$$\text{Fraction of total energy lost in slip} = 1 - \frac{u_L}{u_G} = \frac{u_G - u_L}{u_G} = \frac{u_R}{u_G} \qquad [15]$$

Therefore the slip loss in foot-pounds =

$$\frac{u_R}{u_G}\left[GP_{at} \ln \frac{P_B}{P_T} - kP_{at}L(P_B - P_T)\right] \qquad [15a]$$

In the derivation above, it was shown that the average pressure in the flow pipe should be the logarithmic mean of the terminal pressures. However, as most calculations are made in short flow pipes or in short sections of long flow pipes, the difference between the terminal pressures is not great and the arithmetic mean can be used for the logarithmic mean without seriously sacrificing the accuracy. The use of the arithmetic mean makes the calculations simpler and easier.

Description of Apparatus

The apparatus employed (Fig. 2) was essentially a gas-lift with provision for measuring the fraction of the pipe occupied by liquid under given conditions. The equipment was set up in a derrick in the Sugarland field.

The liquid used was contained in two measuring tanks, 2 ft. 6 in. dia. and 5 ft. high. Connections to the pump were arranged so that the liquid could be pumped alternately from the two tanks and were provided with quick-closing valves so that the change from one tank to the other could be made instantaneously. Two pumps were provided: a 5-hp. Viking rotary pump and a 15-hp. centrifugal pump, which was used as a spare. The rate of liquid flow through the vertical pipe was regulated by means of a by-pass line between the intake and discharge lines on the pumps. The liquid was discharged into a 4-in. header, from which connections to the individual flow pipes were made.

Gas was supplied from the field fuel system. Gas volumes were measured with a recording metric orifice meter. In order to eliminate the necessity of frequently changing the orifice plate, two orifice flanges were installed in parallel lines and the meter connected to both sets of

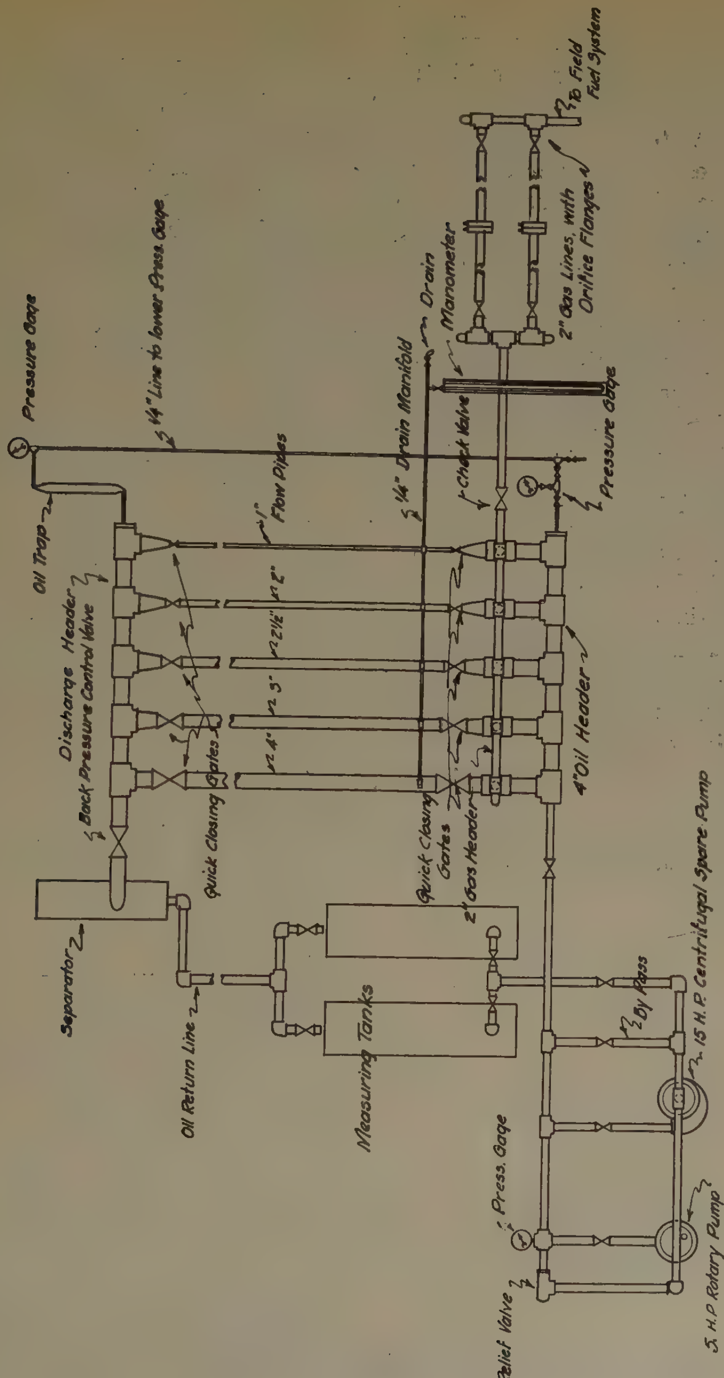

FIG. 2.—APPARATUS USED IN EXPERIMENTS.

flanges. By this arrangement gas could be measured through either plate by simply opening a few valves and closing others.

Five flow lines were provided: 4, 3, 2½, 2 and 1 in. Each line was composed of three joints of pipe, making it 67 ft. 3 in. long. Near the bottom and top of each line, quick-closing valves were provided and by closing these valves simultaneously the oil in the pipe between them under a given set of conditions could be trapped and measured. At the base of the columns, a ¼-in. manifold was connected to each flow line and to a 50-in. mercury manometer. Thus the hydrostatic head of the oil trapped in the pipe by closing the valves could be measured, and from this the volume of oil in the pipe could be calculated. This was checked, in many instances, by draining the oil out of the flow pipe into suitable measures.

The upper ends of the flow pipes were connected into a header, attached to a small separator. By adjusting a valve on this header, the back pressure on the apparatus could be regulated. The gas from this separator escaped to the atmosphere, whereas the liquid returned to the measuring tanks.

Pressure gages were installed on both top and bottom headers. By means of a ¼-in. line running from one manifold to the other, the pressure at either the top or bottom of the columns could be read from the derrick floor. An attempt was made to read these pressures by means of manometers, but the pulsations made this very difficult. For this reason, all pressures were measured by means of gages, which were calibrated at regular intervals.

Experimental Procedure

In the experimental work, five liquids were used: water, kerosene, heavy gas oil, light lubricating oil, heavy lubricating oil. The properties of these liquids are given in Table 1.

Table 1.—*Properties of Liquids Tested*

	A. P. I. Gravity, 60° F.	Kinematic Viscosity, Centipoises per Sp. Gr.			Surface Tension Dynes per Cm. at 78° F.
		50°F.	77° F.	100° F.	
Water		1.3	0.9	0.7	71
Kerosene	41.8	3.2	2.4	1.8	27
Gas oil	27.4	Solid	63.0	14.0	29
Light lubricating oil	23.3	84.0	35.0	18.0	29
Light lubricating oil	21.7	High	106.0	49.0	30

The reason for using refined oils in preference to crude oil was that weathering has little affect on the refined oils but causes marked changes in the viscosity and gravity of most crudes.

TABLE 2.—*Tabulated Data*

Run	D	A	G	G'	L	y	x	V'	P_B	P_T	ΔP	ΔP_L	ΔP_U	ΔP_F	u_L	u_G	u_R	S	Percent Slip = u_R/u_G
A-1-2	1"	.006	31.2	15.7	0.857	0.226	0.292	12.8	29.0	0	29.0	6.6	0.2	22.2	10.5	56.1	45.6	0.99	81.5
A-1-3	1"	.006	36.8	24.2	0.396	0.163	0.195	22.2	15.5	0	15.5	4.7	negl.	10.8	6.7	80.2	73.5	1.00	91.5
A-1-5	1"	.006	41.6	28.2	0.262	0.098	0.109	25.8	14.0	0	14.0	2.9	negl.	11.1	7.4	86.6	79.2	1.00	91.2
A-1-6	1"	.006	4.10	2.51	0.68	0.44	0.785	1.63	18.5	0	18.5	12.8	"	5.7	4.3	12.4	8.1	1.00	65.2
A-2-1	2"	.0232	22.9	15.2	3.57	0.378	0.622	9.46	15.0	0	15.0	11.0	0.1	3.9	6.7	17.4	10.7	1.00	61.5
A-2-2	2"	.0232	67.0	17.1	2.00	0.275	0.725	14.3	28.5	17.0	11.5	8.0	0.1	3.4	5.2	16.8	11.6	1.00	69.0
A-2-3	2"	.0232	48.0	40.1	0.746	0.161	0.192	36.2	6.5	0	6.5	4.7	negl.	1.8	3.3	34.1	30.8	1.00	90.3
A-2-4	2"	.0232	36.1	26.0	1.54	0.275	0.380	22.0	11.5	0	11.5	8.0	"	3.5	4.0	25.6	21.6	1.00	84.3
A-2-5	2"	.0232	1.95	1.2	1.58	0.558	1.26	negr.	18.5	0								1.00	
A-2-6	2"	.0232	2.04	1.07	3.70	0.880	7.34	0.57	26.5	0	26.5	25.6	"	0.9	3.0	6.4	3.4	1.00	53.0
A-2-7	2"	.0232	34.8	25.1	3.30	0.288	0.366	16.1	13.0	0	13.0	7.8	0.1	5.1	8.8	24.4	5.6	1.00	22.9
A-2-8	2"	.0232	36.2	28.2	1.18	0.217	0.277	23.9	8.5	0	8.5	6.3	negl.	2.2	3.9	25.6	21.7	1.00	84.6
A-2-9	2"	.0232	34.2	16.6	0.76	0.254	0.34	14.4	20.0	11.0	9.0	7.4	"	1.6	2.1	15.8	13.7	1.00	86.7
A-2-10	2"	.0232	4.61	2.8	2.38	0.678	2.10	25.8	19.0	0	19.0	19.8	"	negr.	2.5	6.2	3.7	1.00	59.7
A-4-2	4"	.0875	47.1	33.0	4.8	0.396	0.656	25.7	12.5	0	12.5	11.5	"	1.0	2.3	10.3	8.0	1.00	77.6
A-4-3	4"	.0875	23.6	12.5	0.20	0.641	1.18	12.3	21.0	5.0	16.0	15.8	"	0.2	0.07	5.14	5.07	1.00	98.5
A-4-4	4"	.0875	41.4	20.6	0.16	0.425	0.740	[illegible]	[illegible]	8.5	12.5	12.4	"	0.1	0.07	6.75	6.68	1.00	98.9
A-4-5	4"	.0875	31.1	21.0	3.65	0.439	0.782	16.3	[illegible]	0	14.2	12.8	"	1.4	1.56	7.04	5.48	1.00	77.8
A-4-6	4"	.0875	27.6	1.34	0.54	0.870	6.69	1.26	29.0	2.0	27.0	25.3	0.2	1.5	0.12	1.94	1.82	1.00	93.7
A-4-7	4"	.0875	4.78	2.61	2.86	0.839	5.21	2.06	24.0	0.5	23.5	24.4	negl.	negr.	0.64	3.06	2.42	1.00	79.0
A-4-8	4"	.0875	47.0	30.1	9.11	0.480	0.945	20.5	16.5	0	16.5	14.7	"	1.8	3.5	11.1	8.6	1.00	77.5
A-4-9	4"	.0875	43.9	31.2	3.04	0.407	0.686	26.8	12.0	0	12.0	11.9	"	0.1	1.4	9.9	8.5	1.00	86.9
A-4-10	4"	.0875	45.9	30.4	0.40	0.333	0.500	29.6	13.0	2	11.0	9.7	"	1.3	0.23	8.55	8.32	1.00	97.1
B-1-1	1"	.0060	41.1	22.4	0.622	0.127	0.145	18.1	24.7	0	24.7	3.3	0.1	21.3	13.5	71.0	57.5	0.887	81.0
B-1-2	1"	.0060	1.51	0.82	1.05	0.695	2.28	0.36	24.7	0	24.7	17.8	0.1	6.8	4.2	7.4	3.2	0.887	43.2
B-1-3	1"	.0060	33.6	18.2	0.67	0.163	0.195	14.8	24.8	0	24.8	4.2	0.1	20.5	11.4	60.3	48.9	0.887	81.2
B-1-4	1"	.0060	32.6	17.7	0.656	0.177	0.215	14.6	24.6	0	24.6	4.5	0.1	20.0	10.3	59.6	49.3	0.887	82.6
B-1-5	1"	.0060	21.2	9.0	0.262	0.20	0.25	8.0	24.5	15.0	9.5	5.1	negl.	4.4	3.6	31.3	27.7	0.887	88.5
B-2-1	2"	.0060	46.3	31.4	5.65	0.316	0.461	19.3	14.0	0	14.0	8.1	0.3	5.6	12.7	32.8	20.1	0.887	61.2
B-2-2	2"	.0232	26.6	15.7	6.25	0.437	0.776	7.6	20.3	0	20.3	11.2	0.3	8.8	10.2	19.9	9.7	0.886	48.6
B-2-3	2"	.0232	47.8	24.6	4.60	0.303	0.435	14.1	22.3	5.5	16.8	7.8	0.2	8.8	10.8	25.1	14.3	0.887	57.0
B-2-4	2"	.0232	3.63	2.06	3.77	0.748	2.97	0.79	22.3	0	22.3	19.2	0.1	3.0	3.6	5.8	2.2	0.887	37.9
B-2-5	2"	.0232	25.6	21.0	0.531	0.240	0.316	19.3	6.5	0	6.5	6.2	negl	0.3	1.6	19.7	18.1	0.887	91.8
B-2-6	2"	.0232	43.8	34.8	1.03	0.218	0.278	31.1	7.7	0	7.7	5.6	"	2.1	3.4	31.7	28.3	0.887	89.4
B-2-7	2"	.0232	35.6	14.3	0.276	0.226	0.292	13.4	25.0	18.7	6.3	5.8	"	0.5	0.9	13.2	12.3	0.887	93.1
B-4-1	4"	.0875	47.8	37.2	2.04	0.330	0.492	33.1	8.5	0	8.5	8.55	"	negr.	1.2	10.5	9.3	0.887	88.5
B-4-2	4"	.0875	32.6	23.0	4.08	0.446	0.802	17.9	12.2	0	12.2	11.5	"	0.7	1.7	7.8	6.1	0.886	78.1
B-4-3	4"	.0875	50.5	40.0	1.81	0.251	0.346	34.8	7.5	0	7.5	6.6	"	0.9	1.3	10.1	8.8	0.886	87.1
B-4-4	4"	.0875	3.18	1.83	1.90	0.885	7.70	1.58	21.7	0	21.7	22.6	"	negr.	0.4	3.0	2.6	0.888	86.6
C-1-1	1"	.0060	3.44	2.28	1.045	0.465	0.87	1.08	15.0	0	15.0	11.0	0.1	4.0	6.2	11.8	5.6	0.81	47.5
C-1-2	1"	.0060	3.48	2.30	1.08	0.452	0.825	0.99	15.0	0	15.0	10.6	neg.	4.4	6.6	11.6	5.0	0.81	48.0
C-1-3	1"	.0060	3.39	2.24	1.10	0.461	0.855	0.95	15.0	0	15.0	10.9	negl.	4.1	6.6	11.5	4.9	0.81	42.6
C-1-4	1"	.0060	1.59	1.04	0.705	0.554	1.24	0.465	15.9	0	15.9	13.1	"	2.8	3.5	6.5	3.0	0.81	46.1
C-1-5	1"	.0060	4.54	2.50	0.344	0.268	0.367	1.56	16.0	0	16.0	6.3	"	9.7	3.6	9.5	4.9	0.81	51.6
C-1-6	1"	.0060	43.4	28.3	0.671	0.081	0.088	20.6	15.7	0	15.7	1.9	0.2	13.6	23.1	85.4	62.3	0.81	72.9
C-2-1	2"	.0232	22.4	18.7	0.872	0.204	0.257	15.3	6.0	0	6.0	4.9	negl	1.1	3.1	16.8	13.7	0.81	81.5
C-2-2	2"	.0232	24.4	20.2	1.045	0.254	0.340	17.1	6.3	0	6.3	6.1	"	0.2	2.9	19.3	16.4	0.81	84.9
C-2-3	2"	.0232	24.4	20.4	1.54	0.187	0.230	13.7	5.8	0	5.8	4.5	"	1.3	5.9	17.9	12.0	0.81	67.1
C-2-4	2"	.0232	29.9	19.8	6.89	0.365	0.575	7.8	15.0	0	15.0	8.7	0.3	6.0	13.4	22.0	8.6	0.81	39.1
C-2-5	2"	.0232	25.6	17.8	5.50	0.330	0.493	6.6	12.9	0	12.9	7.9	0.2	4.8	11.9	18.9	7.0	0.81	37.0
C-2-6	2"	.0232	25.2	20.3	2.68	0.222	0.286	11.0	7.0	0	7.0	5.3	0.1	1.6	8.6	18.6	10.0	0.81	53.8
C-2-7	2"	.0232	26.6	22.1	1.98	0.187	0.229	13.4	6.0	0	6.0	4.4	0.1	1.5	7.6	19.4	11.8	0.81	60.7
C-2-8	2"	.0232	25.6	21.3	1.51	0.173	0.209	14.1	6.0	0	6.0	4.1	negl.	1.9	6.2	18.4	12.2	0.81	66.4
C-2-9	2"	.0232	25.2	22.1	0.45	0.147	0.172	19.5	4.2	0	4.2	3.5	"	0.7	2.2	18.5	16.3	0.81	88.0
C-2-10	2"	.0232	25.3	19.5	3.18	0.254	0.340	11.2	8.8	0	8.8	6.1	0.1	2.2	8.9	18.6	9.7	0.81	52.1
C-2-12	2"	.0232	41.7	34.9	1.69	0.138	0.159	24.3	5.8	0	5.8	3.3	0.1	2.4	8.8	28.9	20.1	0.82	69.5
C-2½-1	2½"	.0332	24.0	17.0	5.43	0.386	0.628	8.3	12.2	0	12.2	9.2	0.1	2.9	7.1	14.0	6.9	0.81	49.3
C-2½-2	2½"	.0332	30.8	22.9	5.00	0.284	0.397	10.3	10.1	0	10.1	6.8	0.1	3.2	9.0	40.6	31.6	0.81	77.9
C-2½-3	2½"	.0332	32.7	27.1	1.555	0.189	0.233	20.5	6.1	0	6.1	4.5	negl.	1.6	4.1	16.8	12.7	0.81	75.6
C-2½-4	2½"	.0332	30.3	24.1	2.84	0.218	0.280	14.0	7.6	0.3	7.3	5.2	0.1	2.0	6.6	15.4	8.8	0.81	57.1
C-2½-5	2½"	.0332	2.54	1.57	3.34	0.880	7.33	1.11	18.0	0	18.0	21.0	negl	negr.	1.91	6.6	4.7	0.82	71.1

TABLE 2.—(*Continued*)

C-2½-6	2½"	.0332	27.4	6.44	9.55	0.631	1.71	0.87	53.5	42	11.5	15.5	..	..	7.58	8.8	1.2	0.82	13.6
C-3-1	3"	.0513	32.6	23.2	8.56	0.484	0.938	14.1	12.0	0	12.0	11.5	0.1	0.4	5.7	14.6	8.9	0.82	68.4
C-3-2	3"	.0513	35.6	26.2	8.64	0.462	0.860	16.2	12.1	0	12.1	11.0	0.1	1.0	6.1	15.2	9.1	0.82	59.8
C-3-3	3"	.0513	3.60	2.02	6.35	0.965	27.6	1.79	22.9	0	22.9	23.0	negl.	negv.	2.1	18.7	16.6	0.82	88.8
C-3-4	3"	.0513	38.1	8.96	1.41	0.417	0.715	6.99	51.5	44	7.5	9.9	..	..	1.1	5.0	3.9	0.82	78.0
C-3-5	3"	.0513	2.65	1.55	7.75	0.856	5.95	0.25	21.0	0	21.0	20.4	..	0.6	2.9	3.5	0.6	0.82	17.1
C-3-6	3"	.0513	5.46	3.40	8.06	0.700	2.33	negv.	17.9	0									
C-3-7	3"	.0513	4.38	2.97	1.51	0.592	1.45	1.93	14.0	0	14.0	14.1	negl.	negv.	0.83	2.36	1.53	0.82	64.9
C-3-8	3"	.0513	5.42	3.76	1.57	0.577	1.36	2.60	13.0	0	13.0	13.8	..	..	0.88	2.88	2.00	0.82	69.5
C-3-9	3"	.0513	2.32	1.58	0.274	0.579	1.37	1.37	14.0	0	14.0	13.8	..	0.2	0.15	1.21	1.06	0.82	87.5
C-3-10	3"	.0513	41.4	34.8	1.70	0.196	0.244	27.8	5.7	0	5.7	4.7	..	1.0	2.8	14.0	11.2	0.82	80.0
C-4-1	4"	.0875	29.7	21.0	5.80	.469	0.884	14.4	17.[illegible]	0	12.2	11.2	negl.	1.0	2.3	8.4	6.1	0.82	72.6
C-4-2	4"	.0875	2.74	1.53	6.78	.942	16.2	1.11	23.3	0	23.3	22.4	..	0.9	1.4	5.0	3.6	0.82	71.9
C-4-3	4"	.0875	4.07	2.59	1.13	.663	1.97	2.02	16.8	0	16.8	15.9	..	0.9	0.32	1.45	1.13	0.82	77.9
C-4-4	4"	.0875	4.14	2.51	7.84	.750	3.00	0.07	19.0	0	19.[illegible]							0.82	
C-4-5	4"	.0875	4.31	2.56	8.00	.830	4.88	0.92	20.2	0	20.2	19.8	..	0.4	1.8	2.8	1.0	0.82	35.7
D-1-1	1"	.0060	3.72	1.78	1.80	0.554	1.242	0.33	32.2	0	32.2	14.7	0.3	17.2	9.0	11.0	2.0	0.90	18.2
D-1-2	1"	.0060	3.46	1.40	2.92	0.748	2.97	0.42	43.1	0	43.1	19.8	0.5	22.8	10.8	15.5	4.7	0.90	30.3
D-1-3	1"	.0060	3.94	2.08	1.19	0.545	1.20	2.95	26.0	0	26.0	14.4	0.1	11.5	6.0	12.6	6.6	0.90	52.3
D-1-4	1"	.0060	32.8	16.2	0.89	0.153	0.181	11.3	30.0	0	30.0	4.0	0.2	25.8	16.1	52.9	36.8	0.91	69.5
D-1-5	1"	.0060	30.0	14.4	0.92	0.197	0.246	10.7	31.8	0	31.8	5.2	0.2	26.4	12.9	49.5	36.6	0.91	73.9
D-1-6	1"	.0060	31.7	21.0	0.30	0.141	0.164	19.2	15.0	0	15.0	3.7	negl.	11.3	5.9	67.6	61.7	0.91	91.3
D-2-1	2"	.0232	41.5	33.9	0.75	0.181	0.221	30.5	6.5	0	6.5	4.8	..	1.7	3.0	29.5	26.5	0.90	89.7
D-2-2	2"	.0232	31.7	22.7	2.68	0.272	0.374	15.5	11.5	0	11.5	6.5	0.1	4.9	7.0	22.2	15.2	0.90	68.5
D-2-3	2"	.0232	30.0	17.7	6.44	0.372	0.591	6.8	20.5	0	20.5	9.8	0.3	10.4	12.3	20.1	7.8	0.90	38.8
D-2-4	2"	.0232	39.9	23.4	6.55	0.340	0.516	10.7	20.8	0	20.8	9.0	negl.	11.8	13.7	25.4	11.7	0.90	46.0
D-2-5	2"	.0232	27.2	19.5	2.40	0.283	0.394	13.4	11.6	0	11.6	7.5	0.1	4.0	6.0	19.3	13.0	0.90	67.4
D-2-7	2"	.0232	3.00	1.76	2.18	0.716	2.52	0.89	20.8	0	20.8	18.9	negl.	1.9	2.2	4.4	2.2	0.90	50.0
D-2-8	2"	.0232	3.02	1.76	2.42	0.705	2.39	0.75	20.9	0	20.9	18.5	"	2.4	2.5	4.3	1.8	0.90	41.9
D-2-9	2"	.0232	3.02	1.78	2.66	0.744	2.91	0.86	21.8	0	21.8	19.7	"	2.1	2.6	5.0	2.4	0.90	48.0
D-2-10	2"	.0232	4.30	2.40	4.81	0.721	2.58	0.54	23.1	0	23.1	19.0	0.1	4.0	4.7	6.1	1.4	0.90	22.9
D-2½-1	2½"	.0332	43.6	32.4	3.40	0.270	0.370	23.2	10.2	0	10.2	7.1	0.1	5.0	6.3	22.3	16.0	0.90	71.6
D-2½-2	2½"	.0332	48.0	33.8	4.88	0.286	0.400	21.6	12.4	0	12.4	7.5	negl.	4.9	8.6	23.8	15.2	0.91	63.8
D-2½-3	2½"	.0332	25.6	19.5	1.86	0.290	0.408	15.0	9.2	0	9.2	7.7	..	1.5	3.2	13.8	10.6	0.91	76.8
D-2½-4	2½"	.0332	29.1	22.0	2.29	0.281	0.391	16.2	9.5	0	9.5	7.4	..	2.1	4.1	15.4	11.3	0.90	73.4
D-2½-5	2½"	.0332	43.6	37.1	0.284	0.173	0.209	35.7	5.2	0	5.2	4.6	..	0.6	0.82	22.5	21.7	0.90	96.4
D-2½-6	2½"	.0332	22.4	14.2	6.85	0.451	0.822	5.8	17.1	0	17.1	11.9	0.2	5.0	7.6	13.0	5.4	0.91	41.6
D-2½-7	2½"	.0332	4.46	2.50	5.26	0.800	4.00	1.19	23.0	0	23.0	21.1	0.1	0.8	3.3	6.3	3.0	0.91	47.7
D-2½-8	2½"	.0332	2.67	1.51	2.75	0.780	3.54	0.73	22.8	0	22.8	20.6	0.2	2.0	1.8	3.45	1.7	0.91	49.2
D-3-1	3"	.0513	2.30	1.26	3.92	0.865	6.40	negv.	24.1	0								0.90	
D-3-2	3"	.0513	4.37	2.65	2.03	0.759	3.15	2.00	19.0	0	19.0	20.0	negl.	negv.	0.87	3.55	2.68	0.90	75.5
D-3-3	3"	.0513	27.8	20.7	2.18	0.316	0.463	16.0	10.0	0	10.0	8.3	..	1.7	2.2	21.2	19.0	0.90	89.5
D-3-4	3"	.0513	46.0	33.5	4.88	0.292	0.413	21.7	11.0	0	11.0	7.7	0.1	3.2	5.4	15.3	9.9	0.90	64.6
D-3-5	3"	.0513	41.0	33.0	1.30	0.224	0.288	28.5	7.2	0	7.2	5.9	negl.	1.3	7.9	13.8	5.9	0.90	42.8
D-3-6	3"	.0513	46.8	38.9	0.44	0.183	0.224	36.9	6.0	0	6.0	4.8	..	1.2	0.78	15.4	14.6	0.90	94.7
D-3-7	3"	.0513	42.0	30.6	4.62	0.294	0.416	19.5	10.9	0	10.9	7.8	-	3.1	5.1	14.1	9.0	0.90	63.9
D-3-8	3"	.0513	23.7	15.6	6.35	0.477	0.912	8.6	15.3	0	15.3	12.6	0.1	2.6	4.3	9.7	5.4	0.90	55.7
D-3-9	3"	.0513	3.23	1.82	3.44	0.817	4.47	1.05	22.9	0	22.9	21.6	negl.	1.3	1.4	3.2	1.8	0.90	56.2
D-4-1	4"	.0875	42.1	33.2	0.60	0.284	0.397	31.7	7.7	0	7.7	7.5	..	0.2	0.4	8.8	8.4	0.90	95.5
D-4-2	4"	.0875	34.1	24.2	4.65	0.427	0.744	17.9	12.1	0	12.1	11.2	..	0.9	2.1	8.0	5.9	0.90	73.8
D-4-3	4"	.0875	21.8	13.9	6.98	0.565		negv.	16.6	0								0.90	
D-4-4	4"	.0875	30.0	21.1	3.18	0.430	0.755	16.9	12.3	0	12.3	11.3	..	1.0	1.4	7.0	5.6	0.90	80.0
D-4-5	4"	.0875	41.8	31.1	2.61	0.314	0.457	25.4	9.4	0	9.4	8.3	..	1.1	1.6	8.6	7.0	0.90	81.4
D-4-6	4"	.0875	2.50	1.40	2.08	0.860	6.15	1.06	23.0	0	23.0	22.7	..	0.3	0.46	1.88	1.42	0.90	75.5
D-4-7	4"	.0875	4.46	2.52	4.25	0.821	4.59	1.69	22.7	0	22.7	21.5	..	1.2	0.97	2.66	1.69	0.90	63.6
D-4-8	4"	.0875	2.31	1.25	4.45	0.911	10.2	0.81	25.0	0	25.0	24.0	..	1.0	0.92	2.64	1.72	0.90	65.1
D-4-9	4"	.0875	4.70	2.81	0.29	0.721	2.58	2.80	19.5	0	19.5	19.0	..	0.5	0.08	1.90	1.82	0.90	95.7

TABLE 2.—(*Continued*)

E-1-1	1"	.0060	32.4	17.2	0.621	0.157	0.186	13.9	26.0	0	26.0	4.1	0.1	21.8	10.9	56.6	45.7	0.96	80.6
E-1-2	1"	.0060	31.8	23.1	0.032	0.036	0.037	22.2	10.9	0	10.9	1.0	negl.	9.9	2.5	66.6	64.1	0.92	96.2
E-1-3	1"	.0060	3.39	2.38	0.23	0.348	0.534	1.95	12.4	0	12.4	9.3	"	3.1	1.8	10.1	8.3	0.92	82.0
E-1-4	1"	.0060	4.08	2.25	0.85	0.394	0.65	0.94	24.1	0	24.1	10.5	0.1	13.6	6.0	10.3	4.3	0.92	80.5
E-1-5	1"	.0060	3.26	1.62	1.21	0.520	1.08	0.50	30.0	0	30.0	13.9	0.1	16.0	6.5	9.4	2.9	0.91	30.9
E-2-1	2"	.0060	33.5	11.4	1.75	0.319	0.468	7.65	33.5	23.5	10.0	8.4	negl.	1.6	3.9	11.9	8.0	0.91	67.2
E-2-2	2"	.0232	38.8	25.2	3.44	0.266	0.362	15.7	16.0	0	16.0	9.0	0.1	6.9	9.2	24.5	15.3	0.91	62.4
E-2-3	2"	.0232	40.4	30.0	0.99	0.228	0.296	26.6	10.2	0	10.2	6.1	negl.	4.1	3.1	27.7	24.6	0.92	88.8
E-2-4	2"	.0232	4.91	2.94	2.29	0.612	1.58	1.49	19.8	0	12.8	16.4	"	3.4	2.7	5.4	2.7	0.91	50.0
E-2-5	2"	.0232	3.28	1.62	7.14	0.835	5.06	0.21	30.2	0	30.2	22.2	0.2	7.8	6.1	7.0	0.9	0.91	12.8
E-2-6	2"	.0232	63.1	46.2	2.18	0.198	0.247	37.4	11.1	0	11.1	5.3	0.1	5.7	7.8	41.1	33.3	0.91	80.9
E-2½-1	2½"	.0332	33.0	11.3	1.47	0.352	0.644	8.6	33.5	23.0	10.5	9.3	negl.	1.2	2.1	8.8	6.7	0.91	76.1
E-2½-2	2½"	.0332	39.6	27.3	4.11	0.421	0.715	13.4	13.3	0	13.3	11.1	0.1	2.1	4.9	23.7	18.8	0.91	79.3
E-2½-3	2½"	.0332	41.8	31.4	1.26	0.258	0.348	27.8	9.8	0	9.8	6.9	negl.	2.9	2.4	21.2	18.8	0.92	88.8
E-2½-4	2½"	.0332	3.45	2.06	2.08	0.708	2.42	1.20	20.1	0	20.1	18.8	"	1.3	1.5	3.5	2.0	0.91	57.1
E-2½-5	2½"	.0332	4.14	2.50	2.38	0.669	2.02	1.32	19.0	0	19.0	17.8	"	1.2	1.8	3.8	2.0	0.91	52.6
E-2½-6	2½"	.0332	63.8	47.7	2.55	0.221	0.277	38.5	10.0	0	10.0	5.9	"	4.1	5.8	30.8	25.0	0.91	81.1
E-3-1	3"	.0513	32.6	12.9	0.605	0.355	0.550	11.8	27.0	18.0	9.0	9.4	"	negl.	0.55	6.48	5.93	0.91	91.3
E-3-2	3"	.0513	39.8	28.4	4.68	0.319	0.467	18.4	11.8	0	11.8	8.4	"	3.4	4.8	13.5	8.7	0.91	64.5
E-3-3	3"	.0513	41.9	32.0	1.45	0.278	0.385	28.2	8.9	0	8.9	7.5	"	1.4	1.7	14.3	12.6	0.92	88.1
E-3-4	3"	.0513	3.54	2.06	1.92	0.765	3.26	1.47	21.0	0	21.0	20.4	"	0.6	0.81	2.84	2.03	0.91	71.5
E-3-5	3"	.0513	3.81	2.24	2.26	0.745	2.92	1.47	20.5	0	20.5	19.8	"	0.7	1.0	2.8	1.8	0.91	64.3
E-4-1	4"	.0875	33.0	11.2	6.35	0.563	1.29	5.9	37.0	20.0	17.0	14.7	"	2.3	2.1	4.8	2.7	0.91	56.2
E-4-2	4"	.0875	39.0	29.9	0.67	0.314	0.457	28.4	9.0	0	9.0	8.3	"	0.7	0.4	8.2	7.8	0.91	95.1
E-4-3	4"	.0875	23.2	15.1	3.67	0.544	1.19	12.0	15.8	0	15.8	14.6	"	1.2	1.3	6.3	5.0	0.92	79.5
E-4-4	4"	.0875	3.95	2.26	1.66	0.795	3.88	1.83	22.0	0	22.0	21.2	"	0.8	0.4	2.1	1.7	0.91	81.0
E-4-5	4"	.0875	2.25	1.24	2.06	0.872	6.81	0.94	24.0	0	24.0	23.2	"	0.8	0.4	1.8	1.4	0.91	77.6

In making a run, the desired rate of flow of oil and gas was established and the back-pressure was adjusted to the required value. Conditions were kept constant for about 10 min. before taking any data. During this time, oil was pumped from and returned to the same tank. The other tank had been filled with oil and gaged, and after steady conditions were established oil was withdrawn from this tank for a definite length of time, then it was gaged again. Thus the rate of liquid flow was measured. The rate of gas flow was recorded by the orifice meter. Pressures at the top and bottom of the column were noted. Having taken these data, the quick-closing valves at the top and bottom of the column were closed simultaneously. The valve to the ¼-in. manifold was then opened and the head of oil in the column was read on the manometer. When desired, the oil was drained from the column to check the manometer reading.

RESULTS AND DISCUSSION

Table 2 presents the tabulated data. G, L, y, P_B and P_T were observed during a run. From these, the derived quantities x, V', ΔP, ΔP_L, ΔP_u, ΔP_F, u_L, u_G, u_R and percentage of slip loss were calculated.

Unpublished work done by Lewis and Hershey at Massachusetts Institute of Techology has shown by dimensional analysis of the variables involved that the data obtained should be correlated by means

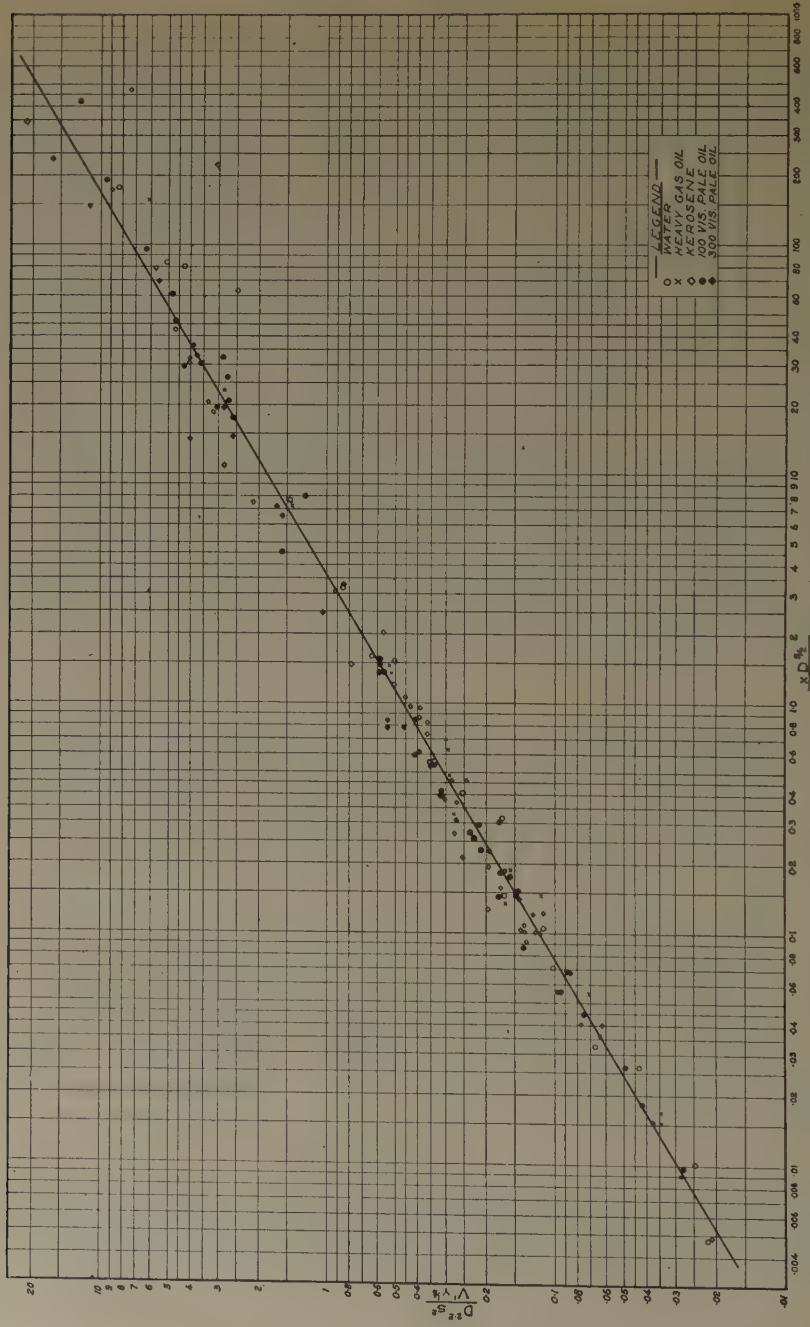

FIG. 3.—CORRELATION OF DATA AS PLOTTED BY AUTHORS.

of the three dimensionless criteria: $xD^{5/6}/V'$, $Dz/V's$, $D\gamma/V'^2s$. Attempts to correlate the data by the use of these criteria failed. Various modifications were tried and the final correlation was obtained by plotting $xD^{5/6}/V'$ against $D^{2.2}s^2/V'\gamma^{1/6}$. Apparently the value of x was absolutely independent of viscosity. Fig. 3 shows how all the points fall on a straight line when the data are plotted in this manner on log-log paper, regardless of the liquid used, its viscosity, liquid or gas velocities, pipe diameter or other conditions. The equation of the curve shown is:

$$\frac{xD^{5/6}}{V'} = 3.58\left(\frac{D^{2.2}s^2}{V'\gamma^{1/6}}\right)^{5/3}$$

This gives the equation for x as

$$x = \frac{3.58D^{1.167}s^{3.33}}{V'^{0.67}\gamma^{0.278}}$$

It is realized that the criteria used are not dimensionless, and thus the theoretical importance of this treatment of the data is lessened somewhat. However, inasmuch as very satisfactory correlation was obtained, the use of the criteria is justified.

From this equation, it is possible to calculate the ratio of the fraction of the pipe occupied by liquid to the fraction occupied by the gas, knowing only the density and surface tension of the liquid, the pipe diameter, the average pressure in the pipe and the quantities of gas and oil flowing through the pipe. Inasmuch as V' is a function of x as well as of L, G and P_{av}, as shown in equation 5, the solution of the equation must be made by successive approximations. A value for x is assumed and substituted in the relationship $V' = G' - \dfrac{L}{x}$ in order to determine V'. This value of V' is used in the solution of the equation for x. This calculation is repeated until the calculated value of x checks the assumed value. Having estimated x correctly, the corresponding value for y is easily found, and the hydrostatic head ΔP_L can be calculated.

The data on friction losses are less accurate. Friction loss was determined by subtracting the hydrostatic head and velocity head from the total pressure drop in the flow pipe. Because the pressures measured showed some pulsation, absolute accuracy could not be obtained. The measurement of the liquid in the pipe was also subject to some error, due, perhaps, to the fact that the two quick-closing valves could not always be closed exactly at the same instant, or perhaps to the existence of a type of flow in which the fluid was composed of alternate slugs of liquid and gas, and thus the pipe did not always contain the same amount of liquid. In most cases, however, the friction loss was much smaller than either total pressure drop or hydrostatic head, and was obtained as the small difference of two large quantities either of which

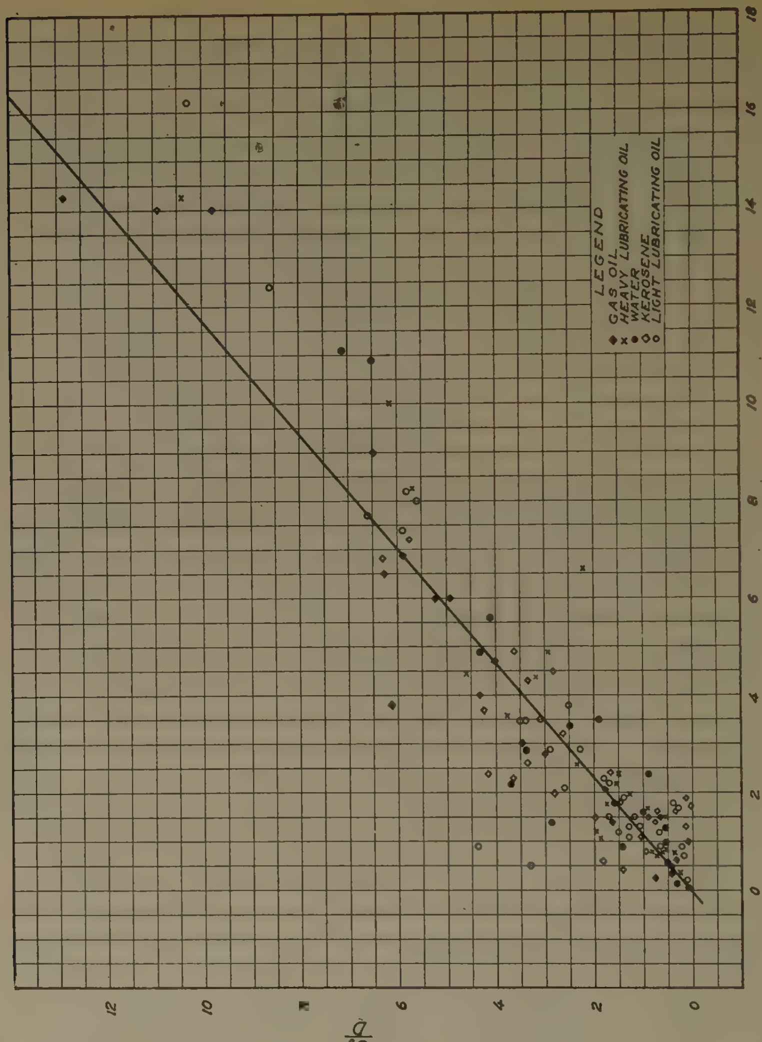

FIG. 4.—CORRELATION OF FRICTION LOSSES FOR ALL PIPE DIAMETERS AND ALL FLUIDS.

may be subject to some inaccuracy in measurement. Therefore it is seen that this term is subject to a fairly large error in its determination. Nevertheless, the data were sufficiently accurate to demonstrate that the Fanning equation could not be applied to the calculation of the friction losses in the flow of heterogeneous fluids. The best correlation of the friction losses for all pipe diameters and all fluids was found by plotting u_L/D against $\Delta P_F/s^3z^{0.18}$ (Fig. 4). From this curve, the following expression for the friction loss per foot of pipe was obtained:

$$\Delta P_F = 0.0125 \frac{u_L s^3 z^{0.18}}{D}$$

This equation is not proposed as a solution to the calculation of friction losses in gas-lift operations. It is simply the best the authors have been able to deduce from the data obtained. It is fairly satisfactory for calculation of friction drops in the experimental lift. The results obtained by this equation are greatly superior to the results obtained by the use of the Fanning equation.

From the relationships developed, it is possible to predict the performance of the experimental lift with reasonable accuracy. It is believed that these relationships can be applied satisfactorily to the design of short lifts. However, attempts to calculate the pressure drops in flowing

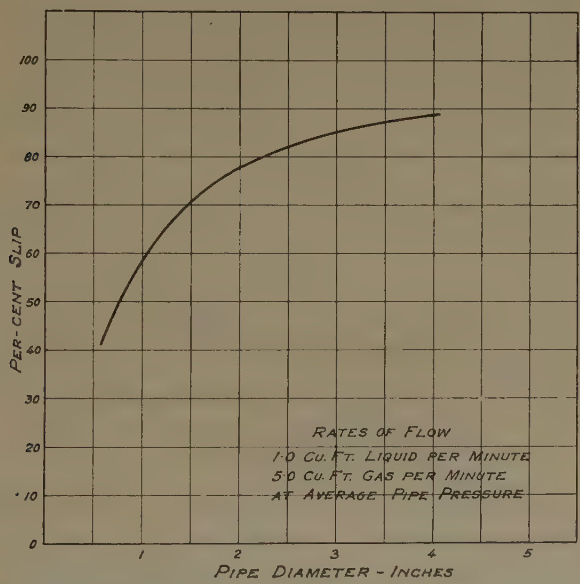

FIG. 5.—VARIATION OF SLIP LOSS WITH SIZE OF PIPE.

or gas-lifted oils wells usually give results that are too high. Apparently more efficient flow is obtained in actual wells than in the experimental apparatus. It is believed that this is due to the longer length of flow pipe in actual wells, rather than to other factors such as the physical properties of the oils or the higher pressures encountered.

Fairly good results have been obtained in flowing wells by using the equation:

$$x = \frac{1.79D^{1.167}s^{3.33}}{V'^{0.67}\gamma^{0.278}}$$

This equation is the same as that determined for the experimental lift, with the exception that the coefficient 1.79 is but half of its experimentally determined value, 3.58.

It is believed that this work shows qualitatively the effect of the various variables in the flow of liquid and gas mixtures. In order to show more clearly the relationship between slip losses and the other variables, typical curves have been prepared to show how, at constant rates of gas and liquid production, slip loss is smaller in small pipes (Fig. 5); to show that in a given pipe, with a constant rate of liquid

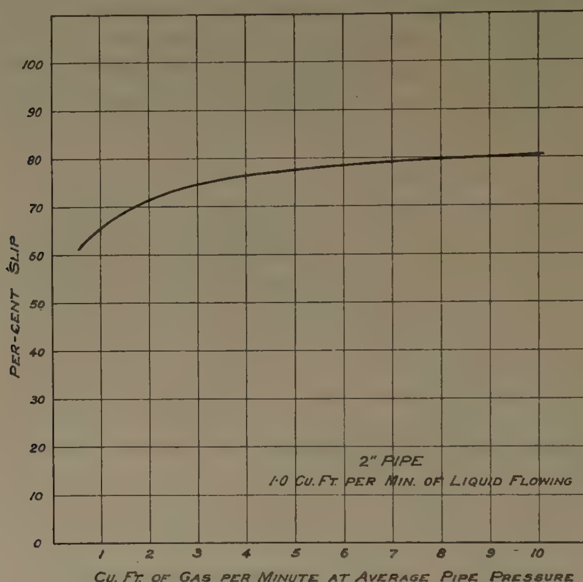

Fig. 6—Effect of rate of gas flow.

production, increasing the rate of gas flow increases the slip losses somewhat (Fig. 6) and to show that for a given rate of gas flow, in a given pipe, increasing the rate of liquid production decreases the slip loss (Fig. 7).

While the results can probably be applied quantitatively to the design of short lifts, further work must be done in order to establish accurately the relationship between the various variables in actual wells.

Conclusions

The purely empirical correlation of the data presented in this paper is valuable because it shows the qualitative relationship between the variables involved. For a given rate of flow of liquid and gas, slip losses are less in smaller pipes; friction losses, of course, are greater. The most efficient flow string is one that so balances the slip losses and friction losses that a given quantity of oil and gas can be carried with a minimum pressure drop. Slippage is not affected by the viscosity of the liquid flowing. It is, however, dependent markedly on the density and to a lesser extent on the surface tension of the liquid.

The quantitative relationships given in this paper can be used satisfactorily in computations dealing with short lifts. They should not be used for accurate calculations on deep wells, although the modified equation proposed can be used where great accuracy is not essential. Nevertheless, the qualitative effect of the various variables is believed to be the same in both the experimental apparatus and the actual wells.

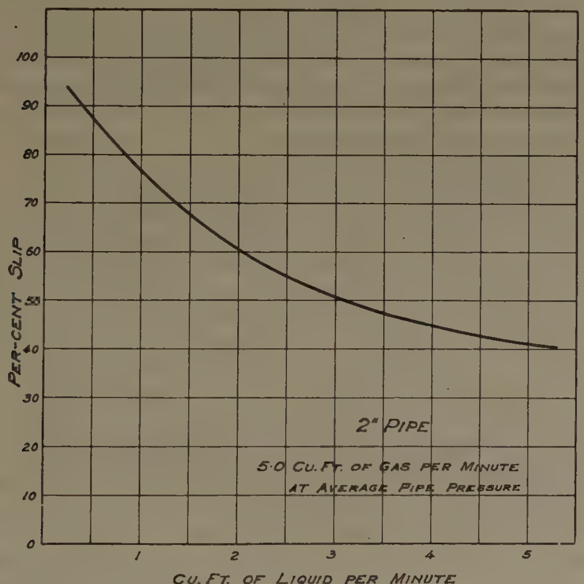

FIG. 7.—RELATION BETWEEN SLIP LOSS AND RATE OF LIQUID PRODUCTION.

In order to determine accurately the quantitative effects of the various variables in actual wells, further experimental work should be carried on in very long lifts. In any such work, it is essential that provision be made for measuring slippage.

DISCUSSION

(*H. H. Hill presiding*)

I. I. GARDESCU,* Pittsburgh, Pa.—I think that everyone agrees that the most important components in computing the pressure drop are the hydrostatic head of the liquid and the friction loss. That is stated at the top of page 299. In the calculation of the hydrostatic head there is one element which the authors seem to have overlooked. Let us take the two extreme cases: If you consider the gas stationary (for instance, assume that the gas bubbles are attached to the walls of the pipe), the pressure at the bottom of the hole will be that of the hydrostatic head of oil equal to RH, R being the

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specific gravity of the oil and H the height of the oil column. In other words, you disregard the fact that there is gas.

The other extreme would be when the gas moves with zero acceleration, the velocity, therefore, being constant. The hydrostatic head in this case will be R_1H; H being the same while the density R_1 would be the specific gravity of the mixture of gas and oil. The head, therefore, will be less. In laboratory experiments as described in the present paper, the bubbles do not start with zero acceleration. You cannot shoot the gas through, and the gas starts with a small velocity, acquiring an increasing velocity until after, say 100, 200, 300 ft. the velocity becomes constant and acceleration zero. Experiments should show a pressure head greater than the condition in which the bubbles are moving at constant velocity and smaller than the conditions in which the bubbles would be stationary. The pressure head, therefore, as computed in the experiments, is greater than in the well, where, for all practical purposes, a uniform velocity of the bubbles may be considered.

L. C. Uren,* P. T. Jones,† and J. W. Johnson,† Berkeley, Calif. (written discussion).—Mr. Moore and Mr. Wilde are to be congratulated on publication of what is believed to be the first experimental study of slippage in operation of the gas-lift, where petroleum and natural gas were the fluids used. This is a difficult problem, the intricacies of which have discouraged other less competent workers. Many different physical variables must be measured and brought under control and their relationships one to another are yet to be defined. The whole subject is deeply involved in advanced hydraulic theory, not overly well understood by most engineers. Though, as the authors themselves state, their work has not reached a stage where quantitative conclusions that may be applied in field practice can be drawn, efforts of this character cannot help improving our understanding of the problems of flowing well and gas-lift operation, and serve in no small degree to stimulate others toward their ultimate solution.

In a preliminary experimental study of this character, many questions necessarily are left unanswered. Even the character of flow with which the investigators had to deal is more or less uncertain. Were they dealing with froths, with mists, or with columns of fluid made up of alternating "slugs" of gas and liquid; or possibly, with two or more of these conditions simultaneously operative? What is to be our physical conception of slippage? Is it due to globules of oil falling through a stream of gas rising more rapidly than the oil globules fall? Is it due to the more rapid ascent of gas bubbles in an upward-flowing stream of oil or froth? Or, is it the result of rapid, channeling flow of gas up through the center of the eduction tube, while oil forming in eddy currents about the gas stream—a liquid cylinder between the gas stream and the steel walls of the tube—is forced upward by the viscous drag of the oil on the gas? We must understand the character of flow that is taking place before we may intelligently deal with the complex problem of formulating the several variables influencing that flow.

Does slippage occur uniformly throughout the length of the eduction tube, or is it confined to certain parts of the tube, or is the effect more pronounced in some parts? Is it greater at the bottom than at the top? At a particular cross-section, is slippage greater at the center of the pipe than near the walls? Later investigations should contemplate exploring different parts of the pipe cross-section and different portions of the eduction tube to find answers to these all-important questions.

Some of the important factors controlling pressure loss are most uncertain. What is the linear velocity of the gas or the oil? There is difficulty in estimating these

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† Senior Petroleum Engineering Student, University of California.

velocities, because we do not know just what proportion of the flow cross-section each occupies. What is the proper viscosity factor to use in such computations? The authors have used the viscosity of the oil, but where we are dealing with internal friction of a mixture of fluids, should we not use a value representative of the viscosity of the mixture, rather than that of one of its components? We know little as yet of the viscosities of these gas-oil mixtures, and yet it would appear to be necessary to obtain some measure of them before a complete solution of the problem with which we are dealing is possible.

The authors note that from the recorded pressure loss, the pressure drop due to hydrostatic head and velocity head of both the oil and the gas must be deducted to determine the pressure loss due to friction and slippage. Other causes of energy loss should also be taken into consideration, though their influence is possibly relatively unimportant. Energy is consumed in forming bubbles of the gas and in atomizing the oil. Entrance losses where the gas enters the eduction tube are probably also significant. The form of the apparatus used is also responsible for certain losses: the reducers at either end of the eduction tubes, 90° turns at top and bottom, static head of oil in the vertical nipples below the gas inlets, and flow irregularities in passing through the quick-acting gate valves, for example. In similar tests now under way, we have avoided these losses by making the manometer connections just above the lower and below the upper quick-acting gate valves. Difficulties mentioned by Messrs. Moore and Wilde in the use of manometers have been, in large part, overcome in our apparatus.

The many sources of pressure loss, apart from friction, and the intangible character of some of them, tend to make results obtained in short flow tubes, such as were used in these experiments, of somewhat uncertain value. The same losses would be experienced in long flow tubes, but the percentage error introduced in the measurements and calculations would be smaller. In planning further work of this character, the desirability of assembling eduction tubes several hundred feet long, possibly in a mine shaft, should be carefully considered. Though such an experiment would be much more costly, it is thought that the results would be considerably more dependable. In such an installation, opportunity could be afforded for determining pressure conditions and sampling the fluids at various levels, and for making observations to determine the character of flow for different gas-oil ratios.

The extent to which the oil becomes saturated with gas in short-tube experiments also may be questioned. Though an intimate admixture of the oil and gas is doubtless achieved, the gas enters and leaves the eduction tube within a few seconds of time, and it is improbable that gas solution effects could be achieved so rapidly.

In view of the many uncertainties in this work, it would seem that the authors' conclusion that the Fanning equation does not apply has not been fully demonstrated. The conclusion that slippage is not affected by viscosity of the fluid is true probably as long as the mist condition prevails, but it is believed that this may not hold where the gas remains occluded within the oil in the form of bubbles, or as a froth. The authors' other conclusions seem well founded.

If this paper has done nothing more than stimulate thought among engineers on this subject, it will have served a useful purpose. Complete formulation of all of the variables controlling flow of gas-oil mixtures through vertical tubes will be achieved only by extensive and thoroughgoing research, with carefully designed and accurately controlled equipment. Messrs. Moore and Wilde have suggested a method of attack and have disclosed most of the difficulties that must be overcome. Later investigators will profit greatly by their effort. Scientific design of tubing installations in free-flowing and gas-lift wells, now conducted almost exclusively on an empirical basis, must await the results of a concerted, organized attack, by highly skilled and adequately financed engineering personnel.

J. VERSLUYS, The Hague, Netherlands (written discussion).—Messrs. Moore and Wilde in a very ingenious way solved the problem of determining experimentally the proportion in which gas and liquid are actually mixed when flowing through a vertical pipe. This was done by means of two quick-closing valves at the top and the bottom ends of the pipe, which were closed simultaneously. This proportion being ascertained experimentally, it is possible to compute the difference of velocity of liquid and gas in the pipe under various circumstances. The writer of this discussion, when writing on Some Principles Governing the Choice of Length and Diameter of Tubing in Oil Wells,[2] had no better data than the figures of the terminal velocity of drops of water sinking in air at atmospheric pressure. In the mixture of gas and liquid rising in a vertical pipe, however, matters are different, on account of the turbulence in the mass. Moreover, it is possible that a thin layer of liquid slips down along the wall of the pipe. Direct measurement of the volume of liquid at any time contained in a section of the pipe, as performed by Messrs. Moore and Wilde, is the only method of determining the mean velocity of rise of liquid. Therefore their paper is a very important contribution to the theory of lifting liquids by gas.

The writer is greatly interested by the fact that pulsation has frequently been observed with the experiments. This may probably be attributed to the unstable condition described in the writer's aforementioned paper.

In expressing the friction loss the writer would deviate from formula 10*a* of the paper. The drop of pressure in pounds per square inch was expressed by Messrs. Moore and Wilde as follows:

$$\Delta P_F = (P_B - P_T) - y\rho_L H$$

In order to find the friction loss as work in foot-pounds per unit of time, in the writer's opinion it would suffice to multiply ΔP_F with the total volume of gas and liquid flowing through per unit of time. This volume equals $L + G$, so that one may write:

$$\text{Friction loss} = P_B - P_T - y\ \rho_L H)(L + G)$$

whereas the formula 10*a* of the paper could be written as follows:

$$\text{Friction loss} = (P_B - P_T - y\rho_L H)\frac{L}{y}$$

The difference can be explained as follows. Messrs. Moore and Wilde obtained the total rate of flow by dividing the rate of flow of liquid by y. This, however, would mean that gas was flowing through at the same velocity as liquid.

The second term on the right of equation 13 for the isothermal work should be omitted. This second term with the negative sign has been added in order to allow for the gas in solution, which should perform no work. The writer, however, stated when deducing formula 51 of a former paper,[3] "By the pressure of the gas, two kinds of work are performed, which, however, according to a previously deduced rule, is equal to the work performed in case all the gas were free and expanded between the same limits."

The rule was deduced in a paper[4] which is not easily accessible and therefore an excerpt of it is given.

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[2] See page 279.

[3] J. Versluys: Reference of footnote 1.

[4] J. Versluys: The Potential Energy of the Gas in Oil-bearing Formations. *Proc.* Royal Academy of Sciences, Amsterdam (1928) **31**, 415–418.

"Should a volume of oil g be under a pressure p and should it be saturated with gas at that pressure, the coefficient of absorption being α, that volume of oil would contain a quantity of gas, which would occupy at unit of pressure a volume

$$\alpha pg \qquad [1]$$

"If the pressure declines by dp a certain quantity of gas would be liberated, occupying at unit of pressure a volume

$$\alpha g dp \qquad [2]$$

and at the prevailing pressure p:

$$\alpha g \frac{dp}{p} \qquad [3]$$

"The volume of the oil and the gas associated with it, being g at the beginning, is increased by the volume expressed under [3]. The isothermal work performed by the gas is then

$$dW_1 = \alpha g dp \qquad [4]$$

"If the pressure declines from P_2 at which the oil is saturated with the gas it contains, to a pressure P_1, in this manner, *i. e.* at being liberated, the gas will perform an amount of work, if the process is isothermal,

$$W_1 = \alpha g(P_2 - P_1) \qquad [5]$$

"As the pressure decreases between those limits P_2 and P_1 the gas liberated while the pressure declined from p to $p - dp(P_2 > p > p - dp > P_1)$, will still expand owing to the pressure declining from $p - dp$ to P_1. The work performed by the quantity of gas, which would occupy the unit of volume at unit of pressure, should the pressure decline from P_2 to P_1 is:

$$\log_n \frac{P_2}{P_1} \qquad [6]$$

according to a familiar formula.

"Hence the quantity of gas liberated between the limits of pressure p and $p - dp$ would, by expansion owing to the decline of pressure from $p - dp$ to P_1, perform work:

$$dW_2 = \alpha g \log_n \frac{p}{P_1} dp \qquad [7]$$

"The work performed by the expansion of the gas liberated while the pressure declines from P_2 to P_1 is:

$$W_2 = \alpha g \left\{ \int_{P_1}^{P_2} \log_n p dp - \log P_1 \int_{P_1}^{P_2} dp \right\} = \alpha g \left\{ P_2 \log_n \frac{P_2}{P_1} - (P_2 - P_1) \right\} \qquad [8]$$

"Hence, the total work done by the gas, if the pressure declines isothermally from P_2 at which the oil is saturated to a smaller pressure P_1, is:

$$W = W_1 + W_2 = \alpha g P_2 \log_n \frac{P_2}{P_1} \qquad [9]$$

"The product αPg in this equation is the volume which would be occupied by all the gas originally absorbed in the oil at unit pressure as given by formula 1. Consequently W in formula 9, which represents the total work done, the gas being liberated from the oil between the limits of pressure P_2 and P_1 equals the isothermal work which would have been done if all the gas were free from the beginning and if it had expanded between the same limits. This work of the gradually liberated gas, however, is performed in two manners; *viz.*, owing to the liberation and owing to the expan-

sion." It may be concluded that, when dealing in isothermal processes with the energy of gas, which is partly dissolved, nothing has to be subtracted for the portion of the gas that is dissolved.

Perhaps the results could be corrected by taking the above considerations into account. Then formula 15 for the fraction of energy lost in slippage alters materially.

The writer of this, however, would suggest the following direct method of calculating the results. The amount of work due to isothermal expansion and pressure on the liquid can be computed according to his paper.[5] The sum of these amounts of work equals the sum of the following amounts: the work used in lifting liquid and gas, the work lost through slippage and the work lost on account of turbulence or friction.

If all these amounts of work are taken per unit of time, the work used in lifting is the product of the length of the tubing and the total weight of liquid and gas flowing through per second. The weight of the gas, however, often may be neglected. The energy lost on account of slippage is the product of relative velocity of liquid and the weight of liquid which by the method of Messrs. Moore and Wilde can be measured directly. The relative velocity, which is the difference of velocity of liquid and gas, can be computed, and the writer comes to the same figures as given in the tabulation of the paper under discussion.

The energy per unit of time lost in turbulence or friction resistance cannot be directly computed but it remains after the two first named amounts of work are added and the work used in lifting and lost in slippage are subtracted from the sum.

If the results of run A-1-2 are computed, the writer finds for the work of the isothermal expansion of the gas in the pipe per minute 72,400 ft-lb. and for the energy lost through slippage (assuming that the pipe is 800 in. long) 13,490 ft-lb. per minute. Consequently the energy loss on account of slippage would be 18.6 per cent., whereas the last split of the above tabulation indicates 81.5 per cent.

Moreover, the writer wishes to draw the attention to the useful work. According to the conception of the above paper, it would be negative in most of the runs. This is possible because of the fact that the pressure drop in all the runs is much greater than will ever occur in flowing oil wells or gas-lifts. In the writer's paper mentioned above he expressed his doubt whether "efficiency" can be recommended as the correct term in respect to useful work when liquids are lifted by gas.

T. V. Moore (written discussion).—Dr. Versluys has pointed out that the work performed by a quantity of gas, part of which is dissolved in a liquid, in expanding isothermally between certain pressure limits is the same as that done by the same quantity of gas, none of which is dissolved, in expanding isothermally between the same pressure limits. If the expansion takes place in a closed system—for example, a cylinder and piston—the external work performed by the gas is $\int_{[illegible]}^{v_1} pdv$. In this expression, v is the volume of the system and p is the pressure thereon. Under such conditions, the work performed is independent of the amount of dissolved gas, and Dr. Versluys' statement is entirely correct.

However, in the case of flow through pipes, the energy of introducing and expelling the gas in any section must be considered. Work is required to introduce gas into the section and work is done by its expulsion. The difference between these two is the accumulation of work in the section, and is equal to $d(pv)$. Furthermore, the gas in expanding does work which is equal to $-pdv$. Therefore, the net work performed by the gas in its passage through the section is:

$$d(pv) + (-pdv) = vdp$$

[5] Reference of footnote 1.

It is this expression, vdp, which must be integrated to obtain the net work performed by the gas. Although $\int_{v_2}^{v_1} pdv$ is independent of the amount of the gas that may be in solution, the term $\int_{p_2}^{p_1} vdp$ does depend upon the extent to which gas is dissolved. It is from this term that the expression

$$\text{Work done by gas} = GP_A \ln \frac{P_1}{P_2} - kP_AL(P_1 - P_2)$$

was obtained, and the correction for the dissolved gas must be made.

It is believed that Dr. Versluys' expression for slippage, the product of the relative velocity of the liquid and the weight of the liquid in the section, requires some modification. We have found that his expression must be multiplied by a factor which is less than one in order to obtain the slippage. In the special case wherein friction losses are negligible, this factor is equal to the fraction of the pipe occupied by gas.

Practical Interpretation of Core Analysis

By L. S. Panyity,* Bradford, Pa.

(New York Meeting, February, 1931)

The inception of this paper may be traced directly to the various discussions of another paper by the writer[1] wherein certain indefinite beliefs and opinions were emphasized as to the relative importance of total sand porosity and the actual size of the openings between the grains. Since publication of that paper it has been possible to study various methods of sand analyses and results that have been obtained under different conditions and actual operations in the field.

The purpose of this paper is to indicate the value of screen analysis, especially in areas where repressuring by means of water-flood, air or gas is being used in the partly depleted fields. Sand samples have been analyzed for porosity, saturation and grain size. They are mainly from the Bradford water-flood area, where a great reliance has been put upon such analyses, and where many data are available. A few sand studies are included from fields other than the water-flood area, in order to indicate the possibilities of screen analysis in any field.

Examples of various conditions are given in Figs. 1 to 7, which show the porosity, saturation and grain-size analyses of submitted cores or drill cuttings. The generally accepted methods of delineating such sand studies on cross-section paper, known as "core charts" has been employed; with the exception that a method of representing grain size has been evolved which is believed to be the best adapted for this purpose. It differs from the block diagrams generally used, in the employment of a linear section. Percentage of grain-size is represented by the subdivision of a given distance, where the total length represents the whole sample of rock chunk, while the subdivisions indicate the percentages of grains of the different sizes that will pass through the various sieves, through which the samples of crushed sand are sorted to determine the size and amount of the components that make up the aggregate. Thus, on Fig. 1, under the heading of Grain Size, the first samples are composed of grains of the following sizes: 16 per cent. through 120-mesh sieve; 33 per cent. through 150-mesh; 25 per cent. through 180-mesh; 26 per cent. through 200 mesh; a total of 100 per cent. A minus sign is placed before

* Geologist and Valuation Engineer.

[1] L. S. Panyity· Valuation of Properties in the Bradford District. Petr. Dev. and Tech. in 1926, A. I M. E. (1927) 238.

the largest size of sieve through which the samples have passed, thus 16 per cent. through −120 indicates that 16 per cent. of the grains have passed through the 120-mesh sieve but would not pass through the next smaller size used. This method makes it possible to represent on one line the porosity, saturation and grain-size analysis of any sample of rock.

It is suggested that the customary method of indicating oil content as a percentage of the total porosity either be eliminated entirely from reports or core charts, or supplemented by another curve showing the

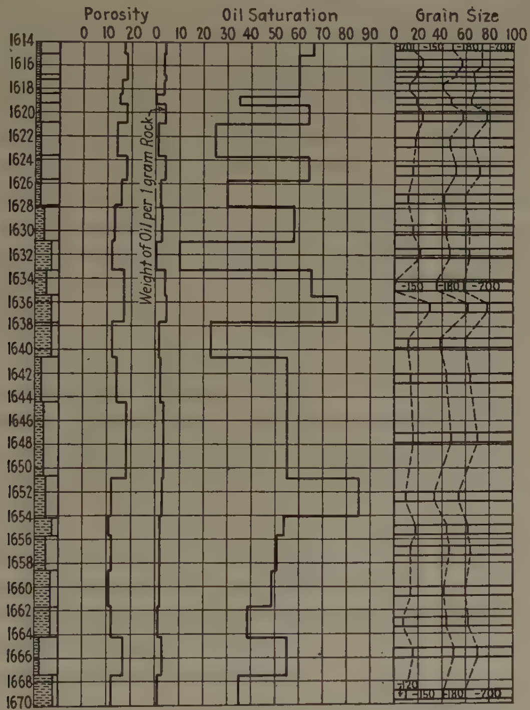

FIG. 1.—CHART OF TYPICAL BRADFORD FLOODING SAND.

oil content in barrels per acre-foot of sand. Such a curve gives a better picture of actual oil content, and is much simpler for the practical oil man to understand.

This paper places a great value upon the interpretation of screen analysis; the writer feels that it is of the utmost importance and outweighs the prominence generally attached to porosity and saturation analyses. It is not intended that such other analyses be discarded; on the contrary, all of them will lead to a better understanding of the phenomena of repressuring.

Laboratory methods of determining permeability by means of pressure have been avoided in this paper, mainly because such experiments carried on in this laboratory have not led to any satisfactory conclusions.

Although other factors may be involved, the size of the sand grains composing an oil-bearing formation to a great extent determine the permeability of that rock with reference to the flow of water, oil, air or gas through its pores. Probably the largest other factor is the cementing material that holds the aggregates together. The cementing material proper will find its way through the smallest sieve and thus will contribute to the percentage of rock classified as −200 on the chart, and this size has a great bearing on the sand's permeability. Screens used in these analyses are mainly those shown on the various charts, and the writer believes that these sizes are sufficient for practical purposes. Fig. 1 shows a typical Bradford flooding sand. The porosity ranges between 11 and 18 per cent. and shows good saturation. The grain-size range is between −120 and −200. The screen analysis shows it to be a fairly even-grained sand body, with a slight tightening at 1635 ft. There is a general increase of the finer grains downward. This writer would consider the ideal flooding sand in Bradford to be composed of about 25 per cent. −120, 33 per cent. −150; 20 per cent. −180 and 22 per cent. −200; porosity about 16 per cent. and good saturation. This chart comes close to these figures. Such a sand should flood normally, and take from 1 to 1½ bbl. of water per foot of sand per day at depths averaging 1500 ft., which is about the average for the field. The uniformity of the entire column indicates that the entire sand body will flood evenly regardless of the various changes in porosity. The columnar section on this chart shows the shale breaks as percentage of the sand body. This method is frequently employed, especially in cases where samples are obtained by methods other than the percussion drill or the diamond drill. The chart is based on the writer's method of sand sampling; which has been used to a large extent in the Bradford field.[2] The line showing the weight of the oil in a unit chunk of rock is to the right of the porosity line and the figures from which it is plotted are calculated in every analysis, although not generally placed on the charts. It is the weight of the oil found per unit weight of rock. In this case the plotted figures are the weight of oil found in 1 g. of sample. Thus at 1620 ft., 1 g. of the crushed sample contained 0.04 g. of oil. This figure is derived by noting the loss of weight of the total sample after solving for oil with carbon tetrachloride. By means of proportion the corresponding amount of oil per gram of rock is obtained. There is a striking similarity between the porosity line and the weight of oil line. In almost every instance an increase of porosity shows a corresponding increase in the weight or amount of oil found in a given sample of sand. The writer believes that a continued study of this relationship will enable

[2] L. G. E. Bignell: Sand Study Becoming More Important. *Oil & Gas Jnl.* (Nov. 7, 1929) 39.

us eventually to determine whether the oil found in the sand on analysis is the natural oil content, whether it is a "banked-up" condition, or whether the oil has been forced in. Much information will be required before this contention may be verified. It is mentioned as a possible line of study. The screen analysis must be considered in this connection, owing to the fact that loss of oil during sampling will vary with the grain size of the sand as well as the viscosity of the oil.

Fig. 2 shows an analysis of the Bradford sand in a different part of the field. The porosity range is between 12 and 18 per cent. On the basis of porosity, the sand would be considered similar to the sample of Fig. 1 for

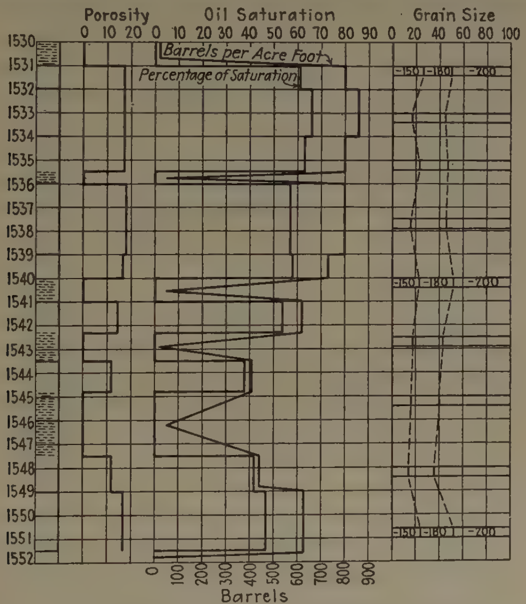

FIG. 2.—ANALYSIS OF FINE-GRAINED BRADFORD SAND.

flooding purposes. The sands, however, are not flooding alike. The answer to this problem is entirely in the screen analysis. The chart shows that the sand is composed of grains not larger than -150, and the percentage of -200 is greater than that shown on Fig. 1. This indicates that this sand will not take water so readily but will need a considerable added pressure. In order to estimate the pressure necessary, the best procedure at this stage of development is to flood the well and note the water intake; then pump water into the sand until the average for the total sand available is from 1 to 1½ bbl. of water per foot of sand per day. The pressure needed may be estimated from the use of constants and empirical formulas. Fig. 2 also shows the saturation according to the suggestion made earlier in this paper. Under the heading of saturation, the line to the left indicates the saturation in terms of percentage of the

porosity, while the line to the right shows the amount of oil reserves in the sand in barrels per acre foot of sand. In this case the increase or decrease of the percentage of saturation is accompanied by a similar increase or decrease in oil content per acre foot. This is not always the case, as these lines often criss cross. Some of the following figures indicate such conditions.

Fig. 3 shows a condition that is difficult to handle under present flooding methods. The center portion of the sand formation is composed of large grains, indicating an open sand body in the center. The increase in grain size is also accompanied by an increase in porosity. Such conditions are frequent in the Bradford sand, but not in all sands, and

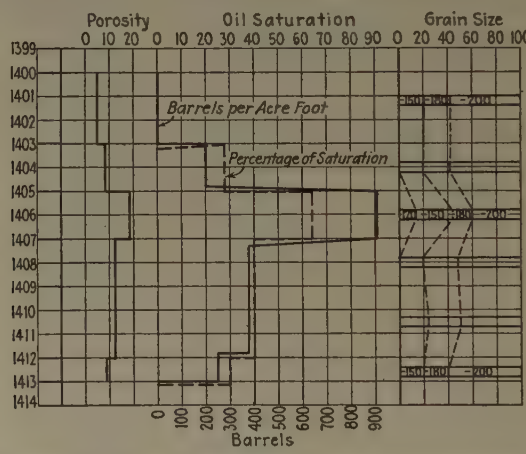

Fig. 3.—Analysis of Bradford sand having central open sand body.

determinations of possible permeability on the basis of porosity will invite danger, whereas such prediction on the basis of grain size will not entail such risk. Sands of this kind are handled best under the so-called delayed flooding method, which will assist the water pressure in the various parts of the sand body to come to an equilibrium. Attempts at packing off such portions of the sand when they occur in the center of the formation have not been successful.

In the area covered by Fig. 4 the actual sand thickness is greater than the chart shows. The lower portion, which is omitted, is very similar to the portion shown from 1690 to 1705 ft. A sudden change is shown by the screen analysis at a depth of 1690 ft. Above this point, the grain-size analysis shows it to be composed of a rather coarse sand; sizes as high as −80 appear in considerable amounts. At 1690 ft. the larger grains disappear and a typical Bradford sand occurs below this point. The porosity range above and below the 1690 ft. point shows no decided variation; the saturation, if it varies at all, is greater above than below. The analysis of Fig. 4 is from the area which the writer believes to have

been erroneously called the "gas-streak" area. It is true that portions of the field near the Knapps Creek dome produced considerable amounts of gas. The portion of the sand above the 1690-ft. point will take a large amount of water. The reason for this advanced by various authorities and oil producers is the presence of the so-called former gas streak; it is not supposed to have had any oil in it, therefore it permits the flood waters to travel through it rapidly and in great volumes.

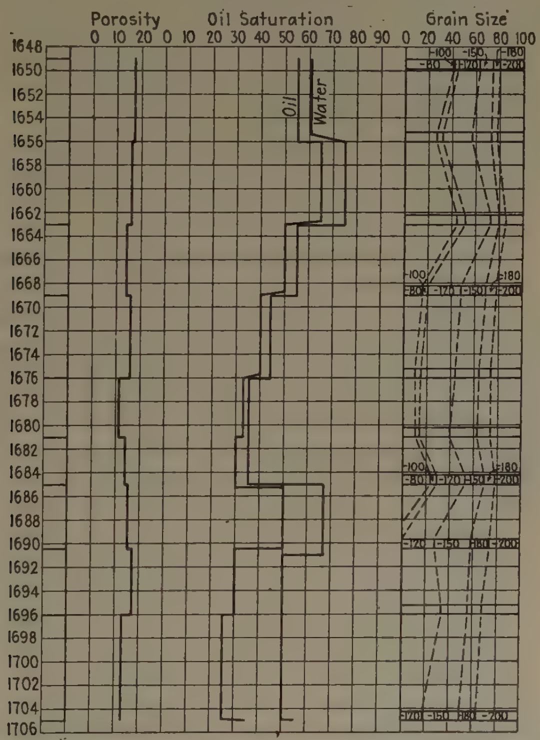

FIG. 4.—ANALYSIS OF BRADFORD SAND SHOWING SUDDEN CHANGE IN GRAIN SIZE.

The writer takes exception to this theory on the following grounds. The presence of gas along the dome is granted but similar conditions are found where the gas occurrence is not known to have been abnormal. The analysis shows the saturation in this portion of the sand body to be similar to that of most other sands in the Bradford field, but the permeability of the sand as indicated by the large grain size is such as to classify the portion of the sand above 1690 ft. outside the category of the typical Bradford sand, and this is the principal reason why such wells often take over 1000 bbl. of water per day. The recovery of oil from these open streaks must be handled in some different manner, as flooding operations as practiced will not recover it, and a great amount of oil is lost.

Fig. 5 shows an analysis of a core taken outside of the Bradford flood area, in a sand other than the Bradford sand where flooding has been attempted with some degree of success. Formerly the production in the area was from wells of the gusher type. The core analysis indicates two separate streaks of sands if studied from the standpoint of screen analysis, while the porosity figures give hardly any basis for drawing any

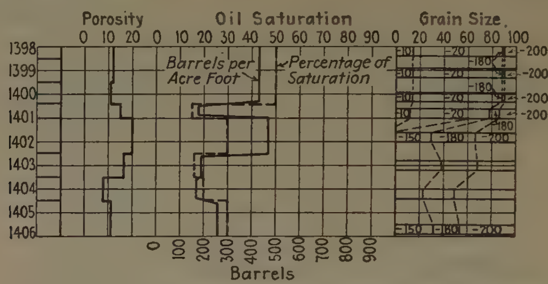

FIG. 5.—ANALYSIS OF CORE TAKEN OUTSIDE BRADFORD DISTRICT.

line of demarcation between the various parts of the sand. Down to 1402 ft., the sand is composed almost entirely of sand grains of the −10 and −20 type, with only a small amount of small-grained sand. Probably the preponderance of the −180 and −200 accounts for the cementing material. Undoubtedly the former large production came from this portion of the sand. The portion below 1402 ft. indicates that the sand

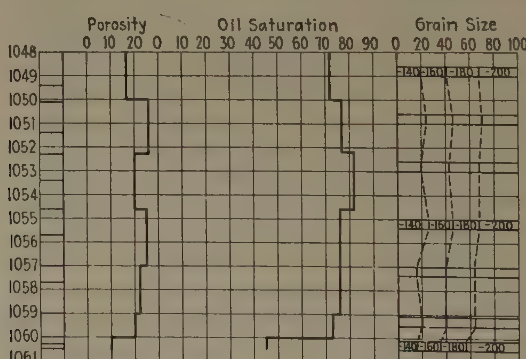

FIG. 6.—ANALYSIS OF A VENANGO SAND.

condition is very similar to the typical Bradford flooding sand, and undoubtedly the flooding results were obtained in this portion of the formation. A study along these lines previous to flooding would have suggested the packing off of the upper portion of the sand, preventing the flow of water through it and flooding only the lower portion of the sand.

Fig. 6 represents the analysis of one of the Venango sands, a uniform sand of high porosity ranging between 17 and 26 per cent. In ordinary

circumstances such a porosity would have indicated that conditions were not suitable for water-flooding. The screen analysis shows a uniform sand body, ranging from −140 to −200. This condition was the reason for the recommendation that an attempt at water-flooding would be justified. An experimental five-spot well was drilled and the carefully kept records of water intake, as well as increase in production, thus far have upheld the contention based upon the screen analysis. The water is being taken at the normal rate under a small added pressure, and the production of oil has been on the increase.

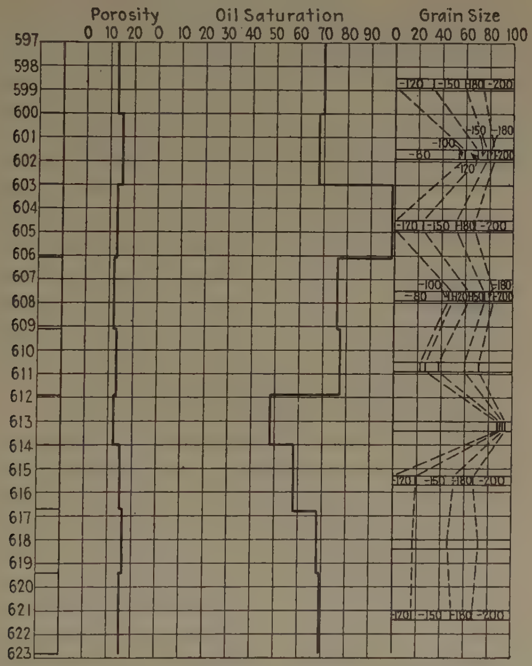

Fig. 7.—Analysis of sand that varies in different horizons.

Fig. 7 is presented to show the possibility of great variation in a sand at various horizons. Such variations may hardly be noted from porosity studies alone, but a different picture is given by the screen analysis. The writer would not recommend flooding operations above the 616-ft. mark.

Conclusion

Not only has the Bradford field found difficulties in certain parts, but flooding operations attempted in many of the older fields throughout the country have met with little success. Conditions under which these experiments were tried are not known, but it would appear reasonable to expect that a thorough sand analysis along the lines laid down here would have given a better light on the various possibilities. Undoubtedly

additional studies along these lines will bring about a better understanding of the movements of oil, water, gas or air through the pores of rocks. The writer believes that the size of the individual pore space, and not porosity, is the criterion for water-flooding, and that it is the controlling factor. Similar reasoning may be justified as to gas and air flooding, if it is generally realized that grain size is the largest factor in determining the permeability of an oil-bearing formation.

Permeability Studies of Pennsylvania Oil Sands*

By Charles R. Fettke† and W. A. Copeland,‡ Pittsburgh, Pa.

(New York Meeting, February, 1931)

The permeability of an oil or gas sand is its capacity for transmitting fluids, either liquids or gases, under pressure. The permeability of a sand depends upon the size and shape of the openings in it and the extent to which these communicate with one another, as well as upon the ratio of their volume to the total volume of the sand.

The apparatus employed and the method of procedure used by the authors in conducting the permeability tests have been described in a previous publication.[1] For the tests described here ½-in. cubes were used. They were set in the lower end of a 1-in. union, inserted in a square hole cut in a hard rubber stopper which fitted into the lower end of the union. In the tests with air, volumes were measured with a wet American gas meter of 100 cu. ft. capacity. In those with water, distilled water at room temperature was employed, unless otherwise noted.

Description of Sands Tested

The tests described in this paper were performed upon 18 samples representing typical oil and gas sands from 7 localities in northwestern Pennsylvania. For purposes of identification, the cores from which the samples came have been designated by capital letters, the sequence of the samples in the cores by numerals, and the individual cubes by small letters. All cubes from the same samples came from adjacent portions parallel to the bedding.

Core *A* of the Bradford sand came from the north central part of the Bradford field, from an area where water-flooding operations have proved highly successful. Core *B* of the same sand was obtained from the southern part of the field. This core contained a so-called "loose streak," 7.5 ft. thick, in the middle portion of which *B*2 is a representative sample. The "loose streak" has given trouble in water-flooding but responded favorably to an air-drive, using a pressure of 300 lb. The natural production was increased approximately five times over a period of three years in which the air-drive was in operation. Core *C*, also of the Brad-

* Published by permission of the State Geologist of Pennsylvania.

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‡ Assistant Professor of Geology and Mineralogy, Carnegie Institute of Technology.

[1] C. R. Fettke and R. D. Mayne: Permeability Studies of Bradford Sand. *Natl. Petr. News* (July 23, 1930) **22**, 61.

ford sand, came from the northern part of the field. *C*1 is representative of 7.5 ft. of so-called "gas sand" which overlies the oil pay in this part of the field, and which has to be packed off when the sand is flooded with water.

Core *D*, of the Venango First sand from Venango County, came from a property where an air-drive with pressures ranging from 60 to 100 lb. has

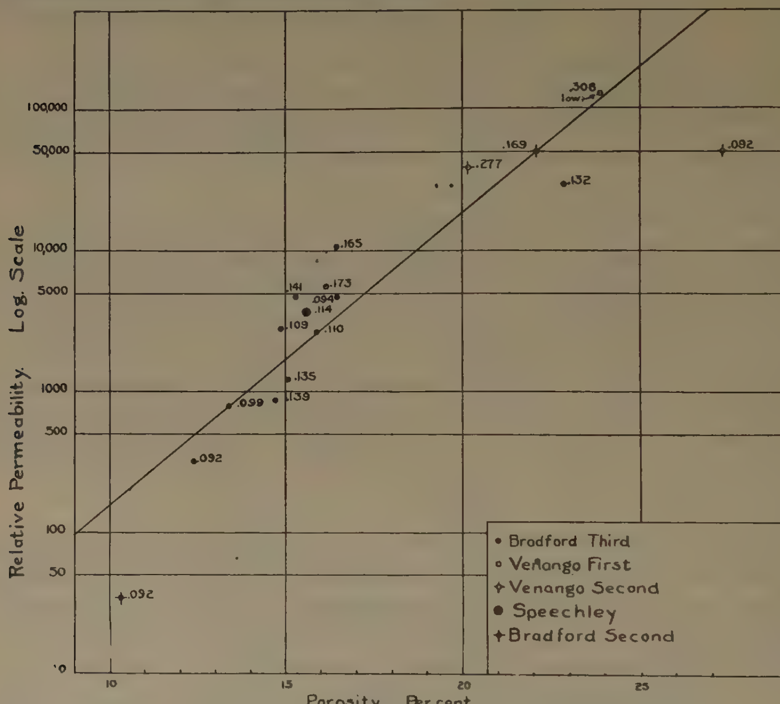

FIG. 1.—RELATION OF PERMEABILITY TO POROSITY WITH AIR. Figures after points represent average grain size in millimeters.

resulted in a recovery of an additional 1800 bbl. per acre over a period of 14 years from wells that had reached their economic limit at the time the air-drive was started. Core *E*, of the Venango Second sand, also from Venango County, came from a tract where an air-drive with a pressure of 325 lb. has resulted in increasing the natural production over four times during the four-year period that it has been in operation.

F is a representative sample of the Speechley gas sand from its type locality in Venango County, and *G* of a sand occurring 215 ft. above the Bradford in the north central part of the Bradford field. It contained only a trace of oil.

PERMEABILITY TESTS WITH AIR

The results of permeability tests with air on 17 of the samples, parallel to the bedding, are shown, plotted on a semilogarithmic graph, in Fig. 1.

TABLE 1.—*Relation of Pressure and Volume of Air Passed through Cubes*

Sample Number	Porosity, Per Cent.	Average Grain Size, Mm.	Temperature at Meter, Deg. C.	Atmospheric Pressure, Mm.	Volume of Air through Sample in 5 Min., Cu. Cm.					Relation with Volume at 15 Lb. Represented by 1.00				
					Reservoir Pressure Above Atmospheric					Reservoir Pressure Above Atmospheric				
					15 Lb.	30 Lb.	45 Lb.	60 Lb.	75 Lb.	15 Lb.	30 Lb.	45 Lb.	60 Lb.	75 Lb.
B1b........	13.4	0.099	19.5	734.2	74	190	374	572	827	1.00	2.57	5.05	7.73	11.18
B2b........	22.9	0.132	20.4	733.2	3,200	8,571	15,206	22,879	31,210	1.00	2.68	4.72	7.15	9.75
B3b........	15.9	0.110	21.1	733.6	246	674	1,246	1,991	2,812	1.00	2.74	5.07	8.13	11.43
D3b.......	23.9	0.308	20.0	741.8	28,146	64,334	104,203	131,714	137,474[a]	1.00	2.29	3.70	4.68	4.88[a]
E2a.......	20.2	0.277	19.9	744.5	4,984	12,373	21,039	30,397	38,906	1.00	2.48	4.22	6.10	7.81

[a] Low because it was impossible to maintain pressure at exactly 75 lb. at the rate at which the air was passing through this cube.

The relative permeabilities are expressed in terms of the number of cubic centimeters of air that passed through the cubes during an interval of five minutes when a pressure of 75 lb. above atmospheric was maintained in the reservoir, calculated to a temperature of 15.6° C. and a pressure of 760 mm. The median line shows the relationship of permeability to porosity. In most instances, sand with grains coarser than those along this line possess permeabilities which fall above the line or, in other words, are higher than those of sands with similar porosities but finer grains, which tend to fall below the line. However, there are several notable exceptions.

TABLE 2.—*Results of Eight Permeability Tests with Water Parallel to Bedding*

Total Time, Min.	Time Interval, Min.	Volume through Sample during Time Interval, Cu. Cm.							
		Sample *A1a* (Por., 15.8 %; Av. Gr. Size, 0.094 Mm.)	Sample *A2a* (Por., 15.5 %; Av. Gr. Size, 0.109 Mm.)	Sample *B2a* (Por., 21.7 %; Av. Gr. Size, 0.132 Mm.)	Sample *D4a* (Por., 15.5 %; Av. Gr. Size, 0.141 Mm.)	Sample *E1a* (Por., 22.1 %; Av. Gr. Size, 0.169 Mm.)	Sample *E2a* (Por., 20.2 %; Av. Gr. Size, 0.277 Mm.)	Sample *E3a* (Por., 27.6 %; Av. Gr. Size, 0.092 Mm.)	Sample *F1a* (Por., 15.1 %; Av. Gr. Size, 0.114 Mm.)
		Reservoir pressure 75 lb. above atmospheric							
15	15	48	22	192	37	800	882	117	33
30	15	41	17	80	29	577	765	39	26
45	15	33	13	61	27	429	630	29	25
60	15	31	17	59	27	348	510	24	21
75	15	30	13	51	26	273	453	22	20
90	15	27	15	50	26	225	304	25	19
105	15	28	15	53	24	180	359	20	17
120	15	27	15	52	24	158	290	20	17
150	30	54	31	98	47	272	445	45	30
180	30	56	31	95	46	198	320	43	26
210	30	55	33	93	45	177	222	38	28
240	30	54	26	87	46	152	108	42	23
270	30	57	30	94	46	135	95	42	25
300	30	54	28	86	47	128	85	45	25
330	30	58	32	86	48	110	75	42	28
360	30	56	30	82	46	108	75	43	30
365	5	Reservoir pressure dropped to 50 lb. above atmospheric							
380	15	20	10	30	14	30	23	15	11
395	15	18	10	24	16	28	14	14	9
410	15	18	10	26	15	32	23	14	9
425	15	18	10	29	15	17	23	12	8
455	30	39	18	52	31	45	39	29	17
485	30	38	20	54	30	41	35	27	17
490	5	Reservoir pressure dropped to 25 lb. above atmospheric							
505	15	9	4	13	7	10	9	10	4
520	15	10	5	11	7	8	9	7	5
535	15	10	5	13	6	9	7	6	4
550		8	5	12	7	8	10	5	3
580	30	18	8	23	14	17	15	15	7
610	30	19	10	23	14	16	17	13	9

The data assembled in Table 1 show that the volume of air passing through the cubes increases at a considerably more rapid rate than the

pressure and that this rate of increase apparently is also dependent upon the grain size and porosity.

Other tests with air showed that in practically every instance the permeability was appreciably less perpendicular to the bedding than parallel to it, and that in some instances there was also a difference in the two directions in the cube at right angles to each other, parallel to the bedding.

Permeability Tests with Water

The results of permeability tests with water on 17 of the samples are shown, plotted on a semilogarithmic graph, in Fig. 2. In each case, the

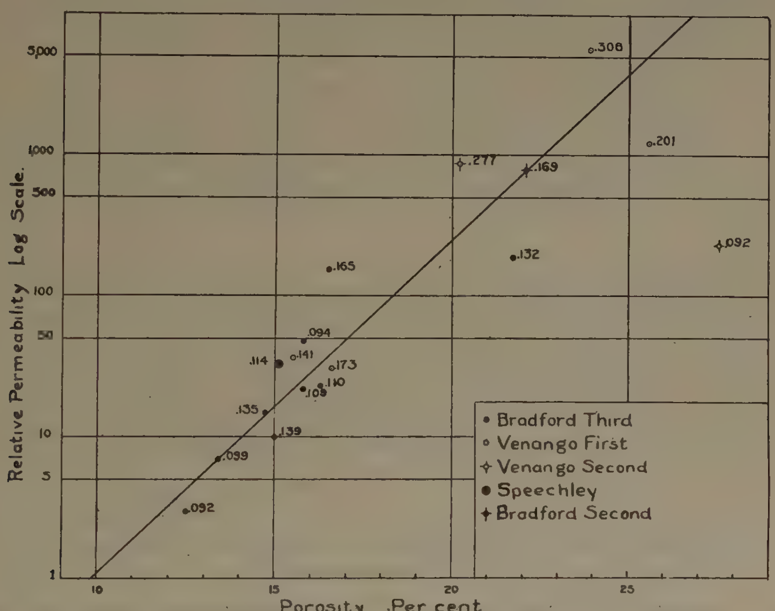

Fig. 2.—Relation of permeability to porosity with water. Figures after points represent average grain size in millimeters.

samples after extraction and drying were placed in the apparatus in the dry state. The distilled water at room temperature entered the cubes at the top and passed down through them parallel to the bedding. A pressure of 75 lb. above atmospheric was maintained in the reservoir above the water by means of compressed air. The relative permeabilities are expressed in terms of the number of cubic centimeters of water that passed through the cubes during the first 15 min. A comparison with Fig. 1 brings out a rather striking resemblance. In both cases, the median lines have been drawn through points representing the same samples.

The results of the tests with water on eight of the samples have been tabulated in Table 2. On the basis of the data in this table, the diagram

of Fig. 3 has been prepared, which shows the relative rate of decline at constant pressure to time. In each case the rate at which the water was passing through the cube at the end of the first 15-min. interval has been called 100, and the relative rates at the end of each of the other intervals have been calculated upon this basis. The decline is considerably less in the less porous, more thoroughly cemented sands than in the more

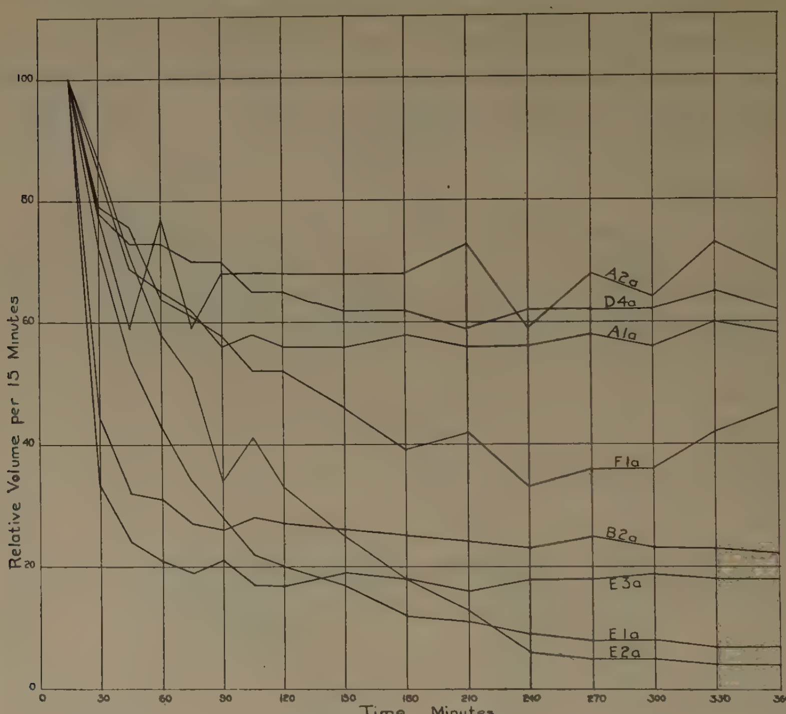

FIG. 3.—RELATION OF TIME AND RATE AT WHICH WATER PASSED THROUGH SANDS.

porous ones and the rate of flow became approximately constant at a considerably earlier stage, also the rate of flow became constant at an earlier stage in the finer grained of the more porous sands than in the coarser ones.

Nutting[2] has published a curve very similar to those shown in Fig. 3, and attributes the cause to some swelling and choking effect in the sand pores. Further on in his article, however, he indicates that another possible cause may be air or other gas dissolved in the water or carried in by it and accumulating in tiny bubbles in the pores, choking them.

[2] P. G. Nutting: Some Physical Problems in Oil Recovery. *Oil & Gas Jnl.* (Nov. 21, 1929) **28**, 44.

The present authors believe that air bubbles are responsible. When the water under pressure enters the dry sandstone at one end it quickly passes through it, by-passing considerable air along the less directly connected pores. In a very short time, however, the water also penetrates these and displaces at least part of the air trapped in them, forcing it into the main channels. Whether or not the water flowing along the latter will be able to carry the bubbles with it and thus keep the passageways clear depends largely upon the shape of the latter. If constrictions occur, the chances are that the bubbles will become lodged at such points and the flow will be interfered with. Air in the form of bubbles, no doubt, also separates from the water as it passes through the sand and acts in a similar manner. The flow becomes approximately constant when, under the pressure-gradient existing, it has become confined to such channels as it is able to keep free from bubbles. When warm boiled distilled water was used, the rate of decline was markedly decreased, but not entirely eliminated. In this case the water was relatively free from dissolved air and was dropping in temperature, so that no air separated from it and bubbles of original air trapped in the sandstone tended to go into solution in it.

If this explanation of the phenomena observed is the correct one, the permeability tests with water yield valuable information in regard to the nature of the openings in the sand. In $A1a$ and $A2a$, which represent Bradford sands that have given excellent results with water-flooding, the decline from the initial rate was much less than that of most of the others and the flow became nearly constant sooner, which would seem to indicate that the channels through them are of more uniform cross-sectional area and hence do not permit bubbles to become lodged along the sides so readily.

The data presented in Table 2 show that the rate of flow of water through the cubes was approximately proportional to the pressure. The deviations from this relationship are undoubtedly due to the same causes that are responsible for the decline in the rate of flow under constant pressure shown in Fig. 3.

Conclusions

In most instances, porosity is a more important factor in determining relative permeabilities than actual grain size in sandstones, but grain size must also be taken into consideration. Actual grain size is only one of the factors involved. The distribution of the grains among the various sizes, the shape of grains, their manner of packing and the degree of cementation are equally important. As the latter factors also have an important bearing on the porosity, they are to a considerable extent reflected in it. In using the permeability-porosity graphs, therefore, it

should be kept in mind that, in general, sands with coarser grains than those along the median line will have higher permeabilities and those with finer grains will have lower permeabilities than the points with corresponding porosities on the median line.

Sands of the type that have given the most satisfactory results in actual practice with water-flooding behaved differently in the permeability tests with water from those in which water-flooding has not been successful or at best only partially so, but in which air-drives at comparatively low pressures (75 to 325 lb.) have resulted in recovering considerable additional quantities of oil after the economic limit of natural production had been reached.

DISCUSSION

(H. H. Hill presiding)

I. I. Gardescu,* Pittsburgh, Pa.—I cannot fully subscribe to Dr. Fettke's assumption that the gas bubbles caused the clogging. In any of these samples, it is true, you find the irregular declining flow curve showing a gradual clogging, but if you reverse the direction of flow through the sample, the clogging element is almost entirely eliminated, showing that the clogging is only superficial. If you introduce two filters and use the same sandstone, using the first filter as a prefilter and taking the data from the second sample only, you obtain a flow with no decline. Clogging by gas bubbles is quite different in behavior.

W. Schriever,† Norman, Okla. (written discussion).—The results stated in this paper are not of the kind from which general conclusions can be drawn, but they may give valuable information concerning the particular sands that were studied. It is unfortunate that much larger samples were not readily obtainable. The paper infers that only one sample of each kind was tested. The results obtained may hold for the respective sands in general, but this is open to question, since ½-in. cube samples are extremely small. The only alternative would have been to test a number of samples from each horizon; the larger the number, the better.

In order that the results of these permeability measurements may be of the most value to other workers in this field, they should be stated in such terms that comparisons with other sands in other regions are directly possible. The tables of data enable such calculations to be carried out, but this would involve much labor on the part of the reader; in fact, the curves of Figs. 1 and 2 would have to be redrawn from the calculated results. Neither in this paper nor in an earlier paper[3] is permeability defined. Evidently it is

$$P = \frac{Vl}{At(p_1 - p_2)}$$

where V is volume of liquid in cubic centimeters, l is length of sand column in inches, A is cross-sectional area of sand column in square inches, t is time in minutes and $(p_1 - p_2)$ is the pressure drop through the sand in pounds weight per square inch.

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* Petroleum Engineer, Gulf Companies; Lecturer in Petroleum Engineering, University of Pittsburgh.

† Professor of Physics, University of Oklahoma.

[3] C. R. Fettke and R. D. Mayne: Permeability Studies of Bradford Sand. *Natl. Petr. News* (July 23, 1930) 61–65.

Just how the location of the straight-line curves of Figs. 1 and 2 were arrived at is not stated. By taking data from these curves the equations for them are respectively:

$$\log_{10} P = \log_{10} 0.809 + 0.226m$$
$$\text{and } \log_{10} P = \log_{10} 0.00492 + 0.235m$$

where P is the permeability and m is the porosity in per cent. When the porosity is zero, there remain permeabilities of 0.809 and 0.00492. However, these are very small, relatively, and may be due to unavoidable errors in reading data from the curves.

Even if the locations of the curves were determined by method of least squares, it is doubtful that they have any great significance, since there were several important variable factors other than permeability and porosity, the most important being grain size and degree of cementation. Seven of the seventeen points plotted in Fig. 2 represent permeabilities from 100 to 400 per cent. greater or smaller than those indicated by the curve at the same porosities. One point indicates a value which differs by 800 per cent. Of these large variations the authors are fully aware.

In view of the work reported last year on spherical-grain sands,[4] it may be expected that the relation between permeability and porosity may be represented, for any one sand, by

$$\log P = a + b \log m$$

where a and b are constants. Qualitatively stated, this means that the increase of permeability with porosity is much less rapid than is indicated by the curves of Figs. 1 and 2. It is possible that these data can be represented better by straight lines on $\log m$, $\log P$ curves than by the m, $\log P$ curves given in the figures. Even if this new function gives a better representation of these data, it is of little significance; it merely means that porosity, mixtures of grain sizes, cementation, etc., have collaborated in this approximate manner for these particular samples.

The authors suggest that the decrease of rate of flow with increase of time is caused by the air trapped in the sand and by air liberated from the water as it flowed through the sand. The second factor, undoubtedly, is by far the more important of these two. In their earlier paper, the authors describe their apparatus. They also state that they used 3 liters of liquid in a vertical tank made of 6-in. pipe. Thus the tank contained only 6 in. of water. The air above the water had a pressure of as much as 75 lb. per sq. in. above that of the atmosphere. All the details of the experimental procedure are not stated, of course, but it is certain that the water would become saturated with the air if sufficient time were given. Even though the diffusion of the air through the water is an extremely slow process, small convection currents must have existed in the water, and some agitation of the water probably occurred when the air was pumped into the tank. It is therefore quite probable that water containing considerable air might reach the sample of sand much sooner than would be possible if diffusion alone took place.

The curves of Fig. 1 and curves in the earlier paper indicate that between 30 and 60 min. elapsed before a noticeable decrease in rate of flow occurred, and that the rates became approximately constant after 4 hr. The sharp variations in the curves can be due to variations of temperature of the apparatus—it was not in a constant-temperature bath. Such temperature variations would cause, for example, changes in viscosity of the water, solubility of the air in the water and convection currents in the water. The last alone might cause very great changes by suddenly changing the kind of water (as regards air content) entering the sand.

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[4] W. Schriever: Law of Flow for the Passage of a Gas-free Liquid Through a Spherical,-grain Sand. *Trans.* A. I. M. E., Petr. Dev. and Tech. (1930) 329–336.

Another cause for the decrease of rate of flow of water through a fine-grained medium was found by Botset.[5] He found that air-free water stored in a glass flask for 46 hr. showed this phenomenon. He attributes the observed facts to the plugging of the porous medium by the products of the hydrolysis of the glass by the water. It is entirely possible that the oil sands used by Fettke and Copeland were not fine-grained enough to be affected appreciably by this phenomenon. If they were, a combination of products of hydrolysis and the air bubbles released in the sand by the pressure drop in the sand must account for the decrease of rate of flow with increase of time.

The authors do not reveal that they took sufficient precautions to supply the same kind of water (as regards air content) to all sand samples at corresponding times. Therefore the shapes of the curves of Fig. 1, between the times of, say, 30 and 240 min., are probably of no great significance. Before 30 min. air-laden water had not reached the sand and after 4 or 5 hr. the water had become saturated and therefore of constant air content. Between these two times, water containing varying, and unknown, concentrations of air reached the sands.

For spherical-grain sands (*loc cit.*) the permeability varies as the grain diameter raised to a power somewhat less than 2, whereas it varies as the porosity raised to a power greater than 4. Thus, with certain restrictions it may be correct to say that "porosity is a more important factor in determining permeability than actual grain size," but it should be possible to select a set of sands that would show a *decrease* of permeability with *increase* of porosity. It is much more nearly correct to say that porosity and permeability are *independent* of one another.

In fact, when the permeability and the porosity of a sand are known, its average pore diameter should be approximately determined. It may be shown that the average pore diameter is roughly proportional to the fourth root of the permeability, divided by the porosity.

C. R. Fettke (written discussion).—The curve of Fig. 1 was drawn in such a way that it would as nearly as possible fall midway between the points shown. Two of the points, 0.099 and 0.169, fall exactly on the line. The curve of Fig. 2 was drawn through points representing the same two samples. On account of the fact that actual grain size represents another important variable factor besides porosity in determining permeability, the authors felt that this procedure was sufficiently accurate to bring out the points mentioned in the paper.

As pointed out by Professor Schriever, if the relative permeabilities are calculated for zero porosity using equations derived from these curves, there still remain very small permeabilities, but in terms of the units employed these are practically negligible. Using the two points mentioned, the equations for the straight-line curves of Fig. 1 and 2 are as follows:

$$\text{Relative Permeability (Air)} = 10^{0.20754m+0.11549}$$

and

$$\text{Relative Permeability (Water)} = 10^{0.23655m-2.32467}$$

When the porosity is zero, there remain permeabilities of 1.304 and 0.0047 respectively, which are in close agreement with the values arrived at by Professor Schriever by reading the data directly from the curves.

Professor Schriever says that his experiments on spherical-grain sands, presumably unconsolidated, indicate that the increase of permeability with porosity is much less rapid than is indicated by the curves of Figs. 1 and 2, and concludes that this difference is due to the fact that porosity, mixtures of grain sizes, cementation, etc., have

[5] Botset: Review of Scientific Instruments, **2**, 84–95, 1931.

collaborated in this approximate manner for the particular samples shown in Figs. 1 and 2. This is undoubtedly true, but as has been stated in the paper, the distribution of the grains among the various sizes, the shape of the grains, their manner of packing and the degree of cementation are all factors that determine porosity and are, therefore, to a considerable extent reflected in it. The oil and gas sands of the Appalachian fields in practically every instance are sufficiently well cemented so that cubes can be readily cut from them. The degree of cementation, of course, has an important bearing upon the porosity.

In the experiments described in the present paper, 6 liters of distilled water were used instead of the 3 liters employed in previous experiments. In each case, the water was allowed to stand overnight so that it would be at room temperature when placed in the apparatus the next morning. The room temperature was kept at approximately 20° C. and rarely fluctuated more than 2° during the course of any particular experiment. The authors do not believe that the marked differences in behavior of samples *A*1*a*, *A*2*a* and *D*4*a* as contrasted with *B*2*a*, *E*1*a*, *E*2*a* and *E*3*a*, shown in Fig. 3, can be explained by temperature variations, as suggested by Professor Schriever.

Microscopic Study of California Oil-field Emulsions*

By Mahmood Abozeid, Cairo, Egypt

(Los Angeles Meeting, October, 1930)

The natural emulsion samples used in this study were shipped directly from twelve California oil fields, through the courtesy of the superintendents of the main producing companies in those fields. Representative parts of each sample were chosen for the slides. Preparation of the slides was generally made in less than two minutes, including time of exposure; in a few cases, about five minutes was required. The short time was intended to minimize the changes in conditions. Whenever comparison was of value, standard conditions were established. Spreading by gravity was adopted instead of smearing. Cover glasses were not allowed to rest on the films.

General Characteristics of Emulsions

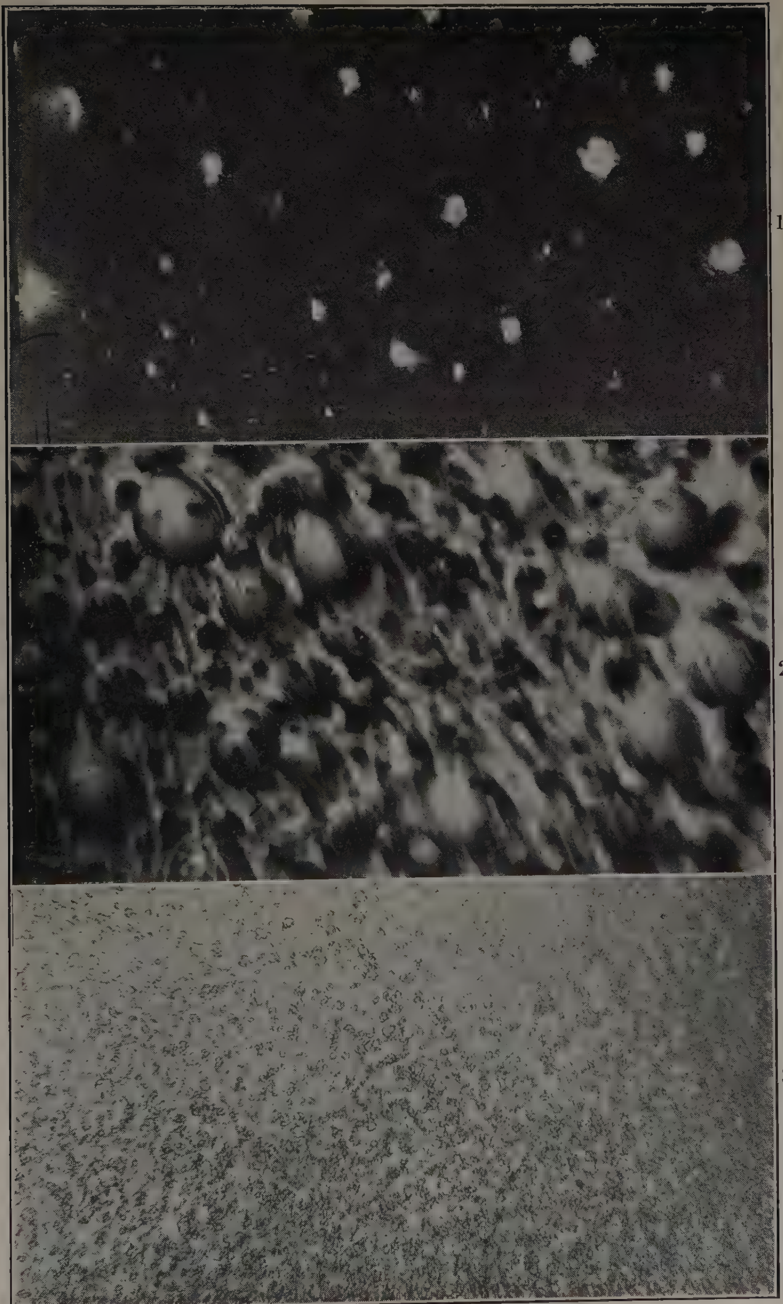
The main purpose of the general views (Figs. 1–16) is to illustrate the general characteristics of the dispersed droplets together with any other constituent or impurity that may be found in each emulsion. The magnification is given so that dimensions could be measured from the plates. The slides used for these views had spherical recesses; they gave the best light. Where crystals were intended to be shown in the picture a filter (green was the best) was usually used. Emulsions that showed a tendency to move by concentrated light were pictured without a condenser.

* This paper constituted part of the concluding chapter of a thesis on A Study of California Oil-field Emulsions submitted by the writer in partial satisfaction for the degree of Master of Science in Petroleum Engineering in 1926 in the Graduate Division of the University of California. The thesis is on file in the main library of the University of California.

Fig. 1.—Coalinga emulsion, general view. × 180.
Gravity, 14.7° Bé. Free water, 2.5 per cent.
Emulsion, 6.5 per cent. Chloride concentration, 0.049N
Emulsified water, 4.9 per cent.

Fig. 2.—Elk Hills emulsion, general view. × 500.
Gravity, 15.7° Bé. Free water, 3.6 per cent.
Emulsion, 9.2 per cent. Chloride concentration, 0.51N
Emulsified water, 8.2 per cent.

Fig. 3.—Buena Vista emulsion, general view. × 180.
Gravity, 25.7° Bé. Free water, 0.8 per cent.
Emulsion, 0.8 per cent. Chloride concentration, 0.593N
Emulsified water, 0.2 per cent.



FIGS. 1–3.—CAPTIONS ON OPPOSITE PAGE.

The arc-lamp light was passed through a water jacket placed over a beaker full of ice. In certain cases it was necessary to surround the jacket with ice from three directions. The thickness of each film of emulsion was governed by its transmittance of light.

The general characteristics of California emulsions may be grouped as follows:

1. Invariably they are of the water-in-oil type.

2. The size of the dispersed water droplets ranges from 10^{-4} to 0.2 mm. Those having a diameter more than 10^{-2} are mostly mechanically suspended. (See Figs. 9, 12, 13 and 14.)

3. The majority contain sodium chloride crystals in the dispersed water droplets. (See Figs. 4, 7 and 14.)

4. All California emulsions contain suspensions of organic matter. Few particles of inorganic matter may be present in some emulsions; they show a dark coating and are not uniformly distributed. (See Figs. 1, 7, 11, 13 and 15.)

5. The arrangement of water droplets is in three forms; separate emulsified droplets with conspicuous films around them which are darker than the oil bulk; separate droplets without films around film; and clusters consisting of very small droplets surrounding and probably holding up a larger droplet. These small droplets swim around the large one, which does not have any protective film. Gas bubbles may or may not be found. (See Figs. 9, 10 and 12.)

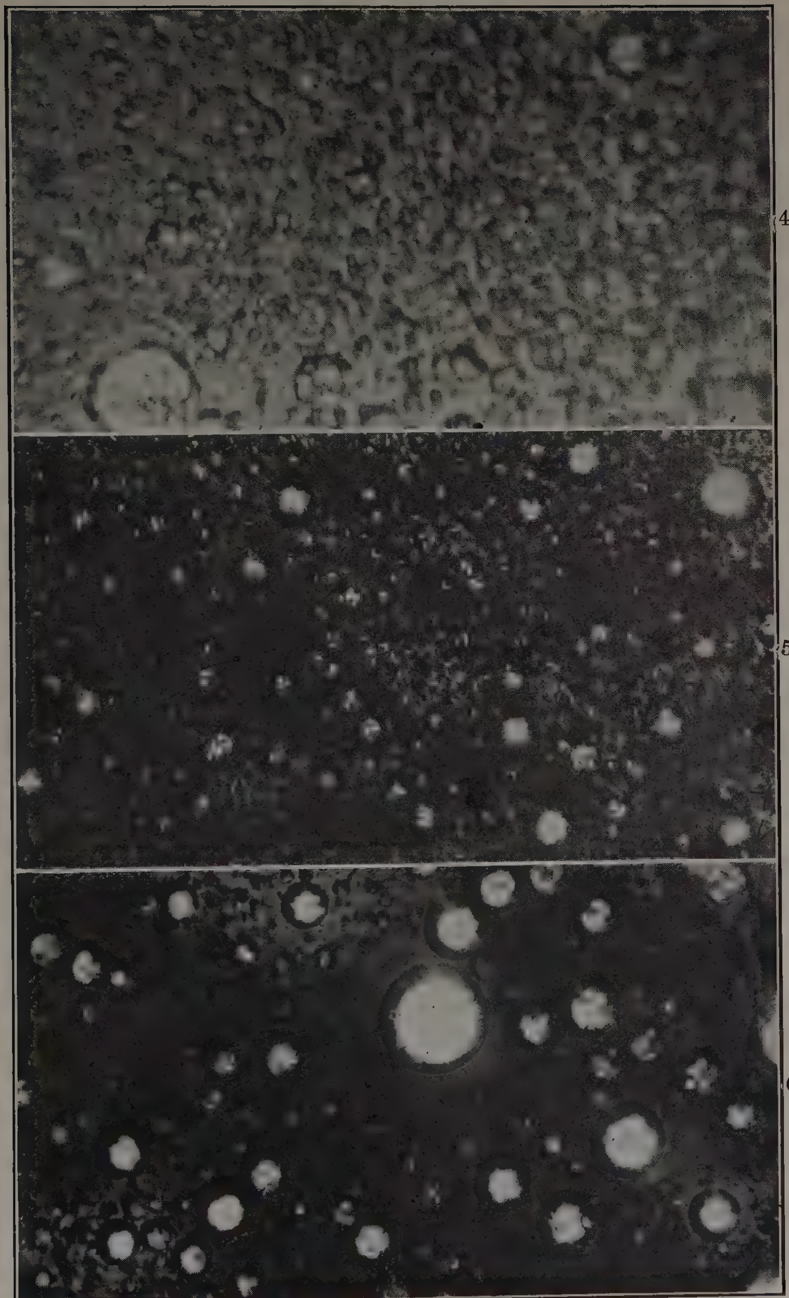
Fig. 1 illustrates the general distribution of the water phase in the emulsified part. The fused and radiating edges of the larger droplets are characteristic of the sample. Even the smallest drops are not perfectly edged spheres. There is a considerable amount of dark precipitant distributed through the oil phase.

In Fig. 2, the general arrangement of water globules is not clear, because of their great sensitiveness to the slightest rise of temperature. This photograph was taken with the arc-lamp light passing through a water jacket cooled with ice from three directions; accordingly there is a probability that light rays might have some effect. With indoors daylight there is no motion and most of the globules are perfect spheres. The smallest water droplets are surrounded by a thicker film of oil, which makes them look like oil globules. The effect of heat on this emulsion is shown in Fig. 17.

FIG. 4.—SAME AS FIG. 3. × 800.

FIG. 5.—MCKITTRICK EMULSION, GENERAL VIEW. × 180.
Gravity, 10.1° Bé. Free water, 12.2 per cent.
Emulsion, 28.0 per cent. Chloride concentration, 0.133N
Emulsified water, 20.0 per cent.

FIG. 6.—COYOTE HILLS EMULSION, GENERAL VIEW. × 180.
Gravity, 24.3° Bé. Free water, 0.8 per cent.
Emulsion, 3.8 per cent. Chloride concentration, 0.231N
Emulsified water, 0.8 per cent.



FIGS. 4–6.—CAPTIONS ON OPPOSITE PAGE.

Fig. 3 illustrates the general distribution of the water phase. In spite of the irregular arrangement and shape of the water droplets they have approximately the same size. Air bubbles are lacking and abnormally large water droplets are very few. Clusters are common. Small isotropic crystals are noticed, which may be seen more clearly in Fig. 4.

Fig. 5 illustrates the general arrangement of the water phase Strained and distorted films are characteristic of this sample. There is no real static motion of the small globules, as the picture hints. One or two crystals could be identified from the negative.

Fig. 6 was focused to show the distribution of the larger droplets. The field was optically isotropic. The interfacial film is rather thin. The surface droplets have smaller diameters than those pictured. Films around the droplets are comparatively thick.

Fig. 7 shows a clear crystal form. The crystals are isotropic and in all probability they are sodium chloride. It should be noticed that the concentration of the sodium chloride in the sample is far beyond saturation. Not all the water droplets show crystal inclusions under the microscope. The magnification and focusing were especially meant to show these crystals. With lower magnification or surface focusing they do not show so clearly.

Fig. 8 shows the distribution of water globules. The sodium chloride crystals are not clear in the print. Compare Fig. 7. For electrical behavior, see Figs. 22 to 28 and for effect of dilution, Figs. 13, 19 and 20.

Fig. 9 was taken mainly to bring out the special relative arrangement of different sizes of water globules. The large clusters are typical examples of the rest. Individual water droplets, small or large, are very few. Small spheres swimming around the larger droplets are mostly water; a very few of them are air. The large droplets are probably held mechanically in the emulsion.

Fig. 10 shows the arrangement of the small globules of water around the large ones. By the application of slight heat the small droplets can move about freely while still enclosing the large ones. Occasional air bubbles are probably intermixed with the small water droplets. Fig. 11,

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FIG. 7.—MARICOPA FLATS EMULSION, GENERAL VIEW. × 800.

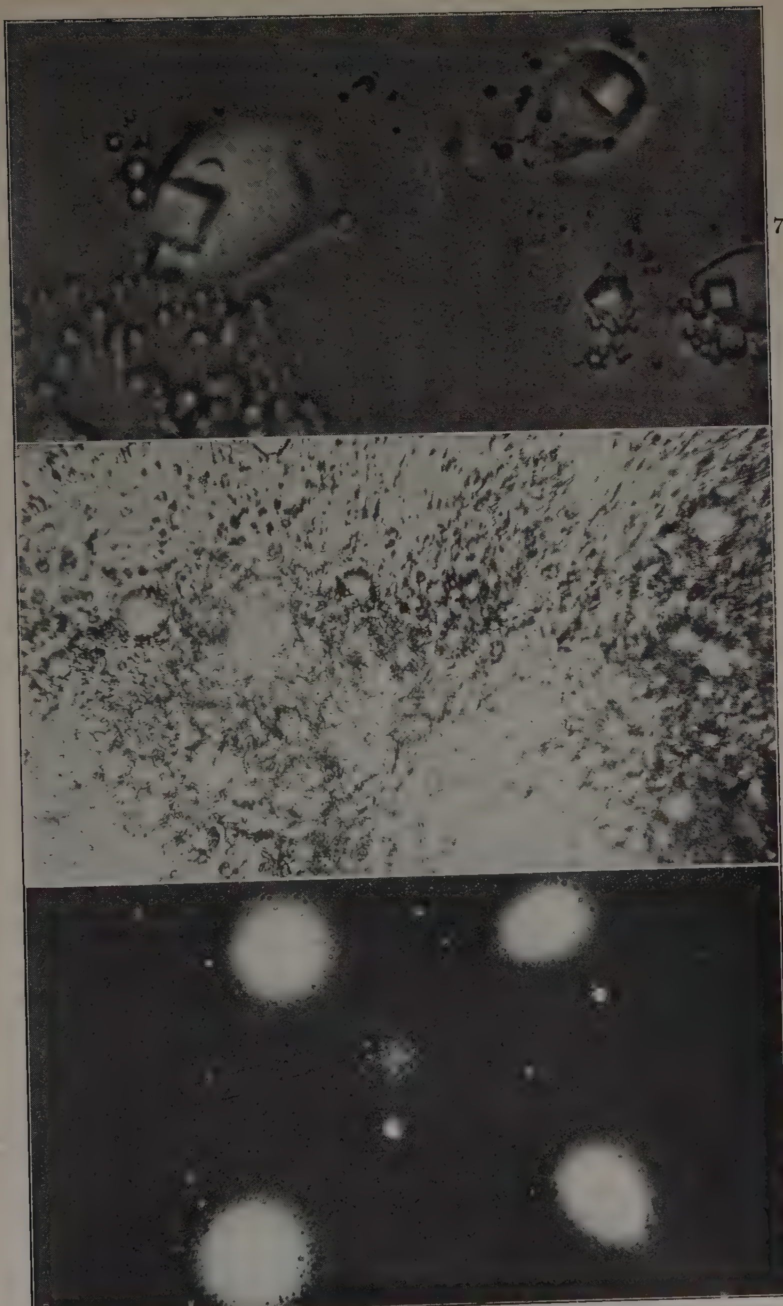
Gravity, 12.2° Bé. Free water, 2.0 per cent.
Emulsion, 54.0 per cent. Chloride concentration, 0.334N
Emulsified water, 43.2 per cent.

FIG. 8.—MARICOPA FLATS EMULSION, GENERAL VIEW. × 500.

Gravity, 12.2° Bé. Free water, 2.0 per cent.
Emulsion, 54.0 per cent. Chloride concentration, 0.334N
Emulsified water 43.2 per cent.

FIG. 9.—SIGNAL HILL EMULSION, GENERAL VIEW. × 143.

Gravity, 19.4° Bé. Free water, 5.0 per cent.
Emulsion, 21.4 per cent. Chloride concentration, 0.492N
Emulsified water, 6.4 per cent.



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FIGS. 7–9.—CAPTIONS ON OPPOSITE PAGE.

at a higher magnification, is focused to show the detail of the small and individual droplets. For the electrical behavoir, see Figs. 24, 30 and 31.

Fig. 12 illustrates the general distribution of the water phase. The exceptionally large droplet is probably mechanically held by the emulsion.

Fig. 13 illustrates the general distribution of the water phase. Probably the largest drops of water are held mechanically by the smaller ones. Black suspensions are common. Films around the small globules are thick.

Fig. 14 was taken with a high magnification in order to bring out more detail. The motion of the globules obstructed the result. In the field of the microscope cubical crystals were seen.

Fig. 15 illustrates the sluggish quality of the sample. The distribution of the water droplets indicates a strange type of emulsion. Some of the black spots are thick films of opaque plastic material, present as coatings of small water droplets or foreign suspensions in the emulsion. The rest are noncrystalline, finely divided suspensions. The sample contains a considerable amount of hydrogen sulfide gas.

Fig. 16 illustrates the general distribution of the water phase. The droplets have irregular shapes and are scarcely spherical. Black suspensions are common.

Heat Effects on Emulsions

Fig. 17 illustrates the action of heat on Elk Hills emulsions. These effects may be grouped as follows:

1. The movements of the dispersed droplets and the suspended organic matter.

2. The coalescence of the droplets on colliding with each other or with mechanically suspended larger ones. A large droplet usually acts as a nucleus of coalescence.

3. Expansion of the films followed by their distortion and coagulation.

4. Expansion of the gas bubbles already found and the formation of others. Expansion is followed by bursting, which injures the films.

5. The decrease of the viscosity of the oil, which will favor coalescence.

The heat used was that of an arc lamp regulated by the condenser of the microscope. The heat convection currents began concentrically with respect to the larger water droplets, as shown in the

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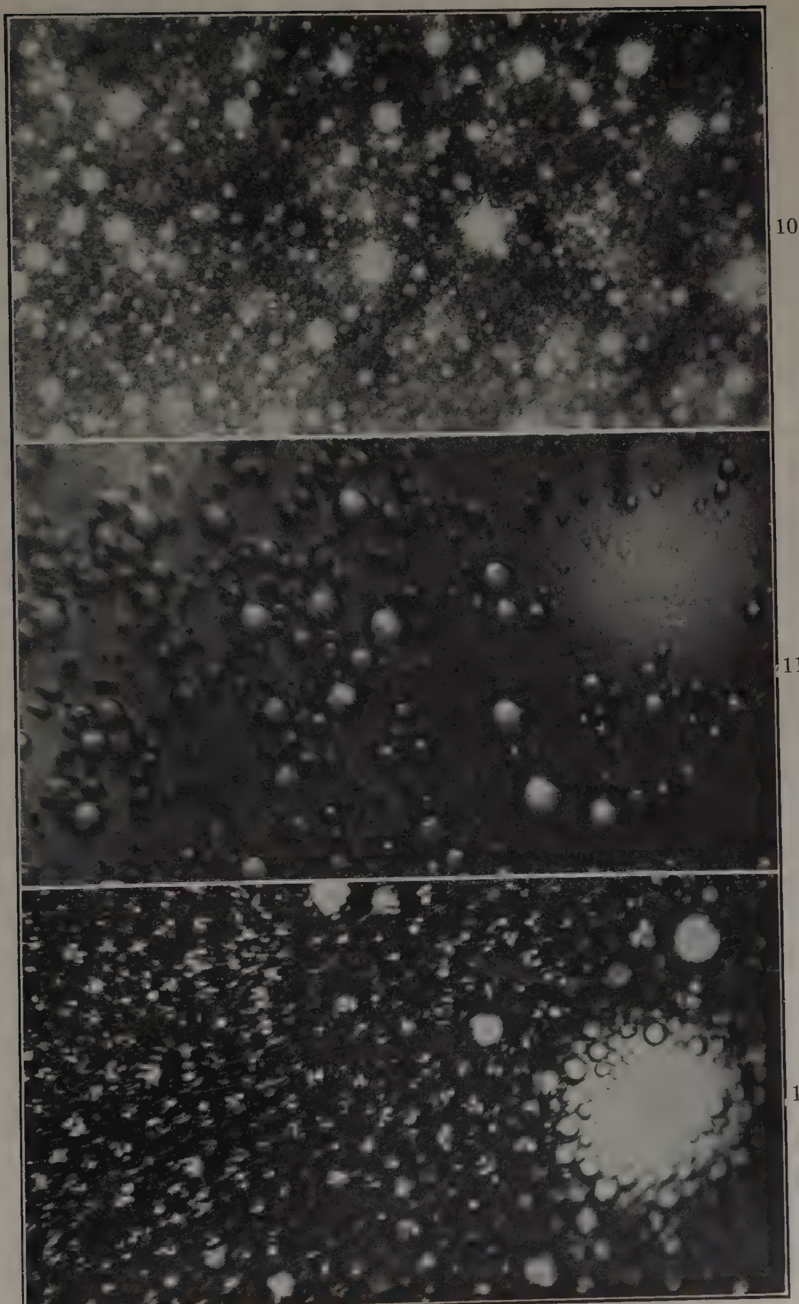
Fig. 10.—Huntington Beach emulsion, general view. × 125.

Gravity, 18.0° Bé.	Free water, 0.8 per cent.
Emulsion, 36.0 per cent.	Chloride concentration, 0.433N
Emulsified water, 27.2 per cent.	

Fig. 11.—Same as Fig. 10. × 800.

Fig. 12.—Inglewood emulsion, general view. × 180.

Gravity, 14.0° Bé.	Free water, 10.0 per cent.
Emulsion, 34.2 per cent.	Chloride concentration, 0.219N
Emulsified water, 30.2 per cent.	



FIGS. 10–12.—CAPTIONS ON OPPOSITE PAGE.

photograph. With rise of temperature the large droplets started to spin around themselves. With further rise of temperature the currents became more rapid and irregular; the small droplets collided into each other; air bubbles increased in number and occasionally burst; the enclosing films were strained, distorted, locally ruptured then coagulated quickly after their enclosed droplets had found their way out. It was noticed that a large water droplet acted as a nucleus into which the smaller ones coalesced.

Dilution Effects on Emulsions

Figs. 18, 19 and 20 illustrate the action of dilution on emulsions from Maricopa Flats. The sample shown in Fig. 18 was first centrifuged and the emulsified portion was used in this experiment. Gasoline was added to the emulsion in equal proportion. The separatory funnels were left in a thermostat kept at 25° C. Vigorous agitation was avoided; the intermixing was effected by oscillating the funnels for 10 min. by the mechanical agitator of the thermostat. The result pictured is a light brown mixture of which 93 per cent. is water. Probably the enclosing film is not soluble in gasoline to a great extent, or else a better separation should have resulted with such a high dilution.

As the gasoline becomes darker than the emulsion after the tenth addition illustrated in Fig. 18, dilution was carried further (Fig. 19). The last result illustrates a form of emulsion that is water clear in color except for a dark thin coating around the water bubbles and occasional dark gasoline droplets. This emulsion, in which the droplets ranged from 3 to 5 mm. in diameter, was left in a beaker for 10 days and showed no further separation. Fig. 19 gives a close representation of the oil film separating three water bubbles from each other. The coating film on one of the droplets is thinner than those on the other two.

Failing to get rid completely of the films around the water globules by the use of gasoline, the same experiment was repeated with the use of benzine. The result did not give any better chance to study the character of this film. There was no complete separation in either case nor complete solubility of the film in either liquid. As a last resort a drop of

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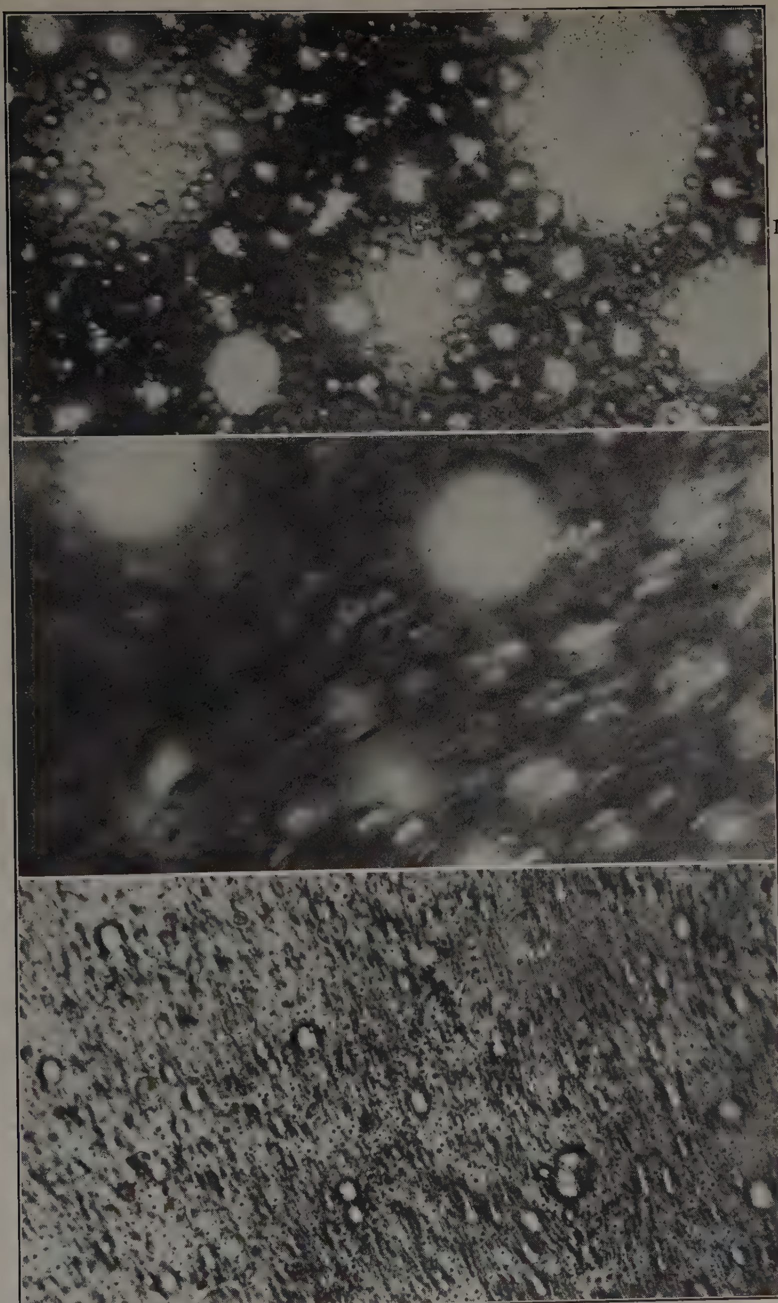
Fig. 13.—Los Angeles emulsion, general view. × 180.
Gravity, 20.7° Bé. Free water, 0.3 per cent.
Emulsion, 5.7 per cent. Chloride concentration, 0.124N
Emulsified water, 3.3 per cent.

Fig. 14.—Torrance emulsion, general view. × 800.
Gravity, 11.9° Bé. Free water, 0.8 per cent.
Emulsion, 19.2 per cent. Chloride concentration, 0.475N
Emulsified water, 14.2 per cent.

Fig. 15.—Casmalia emulsion, general view. × 180.
Gravity, 11.7° Bé. Free water, 25.0 per cent.
Emulsion, 34.5 per cent. Chloride concentration, 0.078N
Emulsified water, 24.0 per cent.



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FIGS. 13–15.—CAPTIONS ON OPPOSITE PAGE.

the emulsion so diluted was allowed to dry. Fig. 20 illustrates the dry films and the nonevaporating constituents of the emulsion. As far as this experiment could show, the film is optically amorphous and dark brown in color. Other constituents of the emulsion are clearly shown.

The conclusions may be grouped as follows:

1. Dilution alone with lighter petroleum products does not break the emulsion completely (Figs. 18 and 19).

2. The protective films are not completely soluble in lighter petroleum products; however, they are more soluble in benzine (Fig. 20).

3. The organic constituents of the emulsions, which are not soluble in lighter petroleum products, are dark in color and noncrystalline in structure. They are probably asphaltenes (Fig. 20).

4. An emulsion may be diluted with as much as 20 times its original volume of gasoline, but a new film will rebuild and prevent the coalescence of the largest droplets (Fig. 19).

Electrical Effects on Emulsion

Figs. 22 to 28 illustrate the sign of the charge on the charged droplets; Figs. 29, 30 and 31 illustrate the effect of higher potential in breaking emulsions.

The slides used for Figs. 24 to 31 were specially made to allow for the presence of both electrodes and the adequate connections. Each slide has three deep cylindrical holes. The central one is 15 mm. dia. and 4 mm. deep; it holds the sample and the two electrodes. On each side there is a smaller hole, 12 mm. dia. and 4 mm. deep, filled with mercury. The electrodes are bent horizontally with the bottom edge of the central hole, in which they are adjustable to form any gap. They run up the walls of the hole, then pass through longitudinal grooves near the upper surface of the slide and terminate in the mercury holes. The mercury connects the slide with outside mains.

The conclusions from these plates may be grouped as follows:

1. Not all the dispersed droplets are charged (Figs. 24 to 28).

2. Charged droplets in California emulsions are *positively* charged (Figs. 22, 23, 25 to 28).

3. Charges are easily reversed if droplets are subjected to high potential difference (Figs. 29, 30, 31).

4. Electric fields of sufficient strength will cause the drops to coalesce, the films to coagulate and the emulsions to break. Heating hastens the electric effects.

5. Direct or alternating current electricity will break the California emulsions.

The current was almost imperceptible and always less than 1 ma. An ordinary U-tube conductivity cell, 1 cm. dia., was used (cell 1, Fig. 21). Faint changes of color in both sides of the tubes were noticed;

the cathode portion was lighter and the anode turned darker. The large water drop shown in Fig. 22 was purposely located in the picture. It is rather abnormal; in fact, it is the only one of its kind that was observed in six slides. Fig. 22 represents the part of the cathode that is 1 cm. below the middle portion and 1 cm. above the platinum tip.

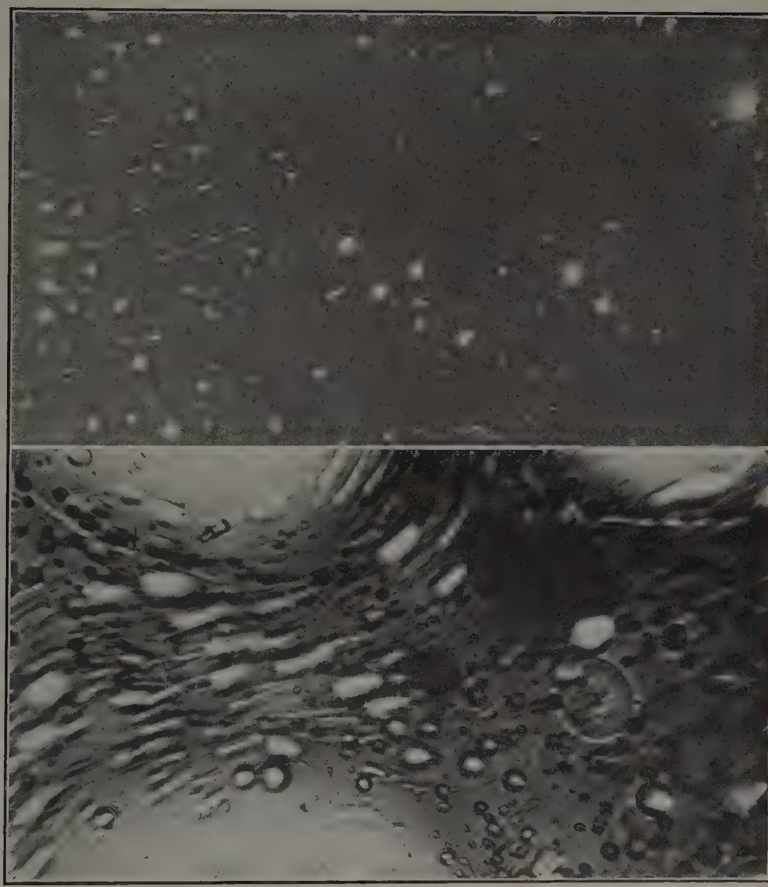

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FIG. 16.—CASMALIA EMULSION, GENERAL VIEW. × 180.

Gravity, 13.2° Bé. Free water, 0.1 per cent.
Emulsion, 34.0 per cent. Chloride concentration, 0.105N
Emulsified water, 20.3 per cent.

FIG. 17.—EFFECT OF HEAT OF EMULSIONS. × 350.

Temperature applied, 38.5° C. Time of exposure, 40 sec.

Fig. 23 shows the cathode portion of the test of Fig. 22. Experimental evidence indicates that the cathode portion contains a considerably larger amount of water droplets than the anode does. The slides pictured were under the same conditions throughout testing and

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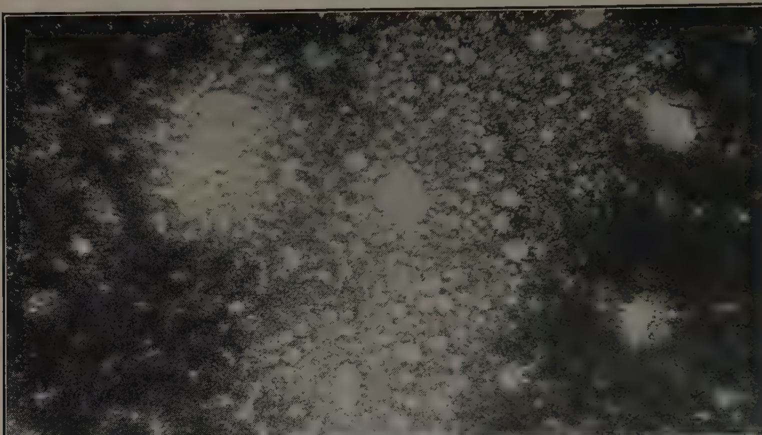

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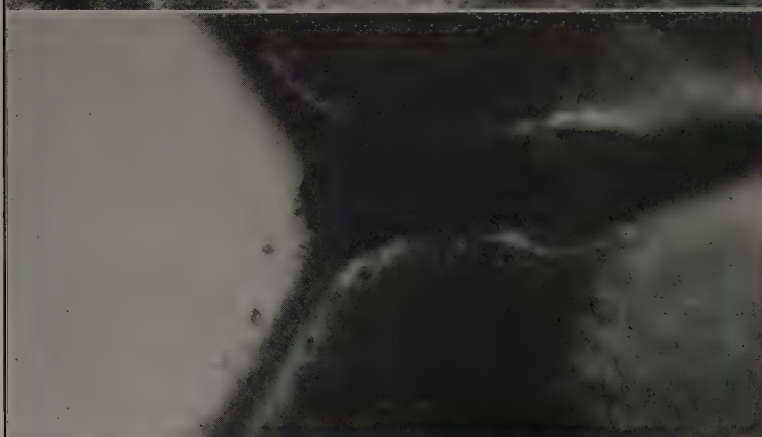

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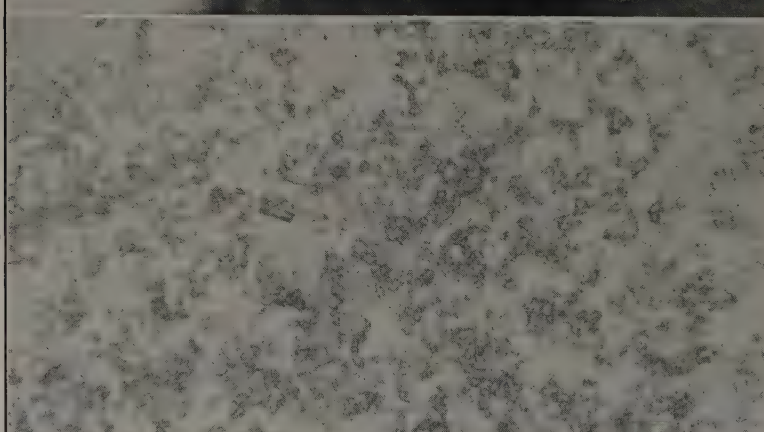


FIG. 18.—EFFECT OF DILUTION ON EMULSION. × 180.
Ten times as much gasoline as emulsion was used.

FIG. 19.—EFFECT OF DILUTION ON EMULSION. × 72.
Twenty times as much gasoline as emulsion was used.

FIG. 20.—DRY-DILUTED EMULSION. × 180.
Ten times as much benzine as emulsion was used.

photographing. The low voltage was intended to avoid any reversal of charge on the water droplets near the platinum tips.

Fig. 24 illustrates both poles under the microscope. The anode is surrounded by oil with very few water droplets; the cathode, barely shown in the picture, is within a medium of larger and numerous globules of water. The motion of the particles was rather slow on account of the low viscosity of the sample. The time of exposure was 30 sec., during which there was no considerable reversal rearrangement of the water globules. Every trial indicated that most of the water globules travel towards the cathode.

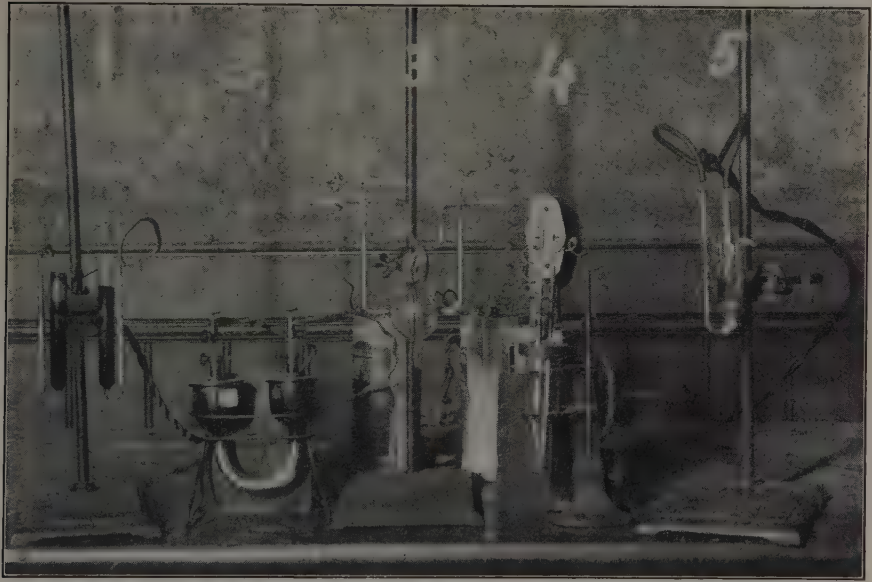
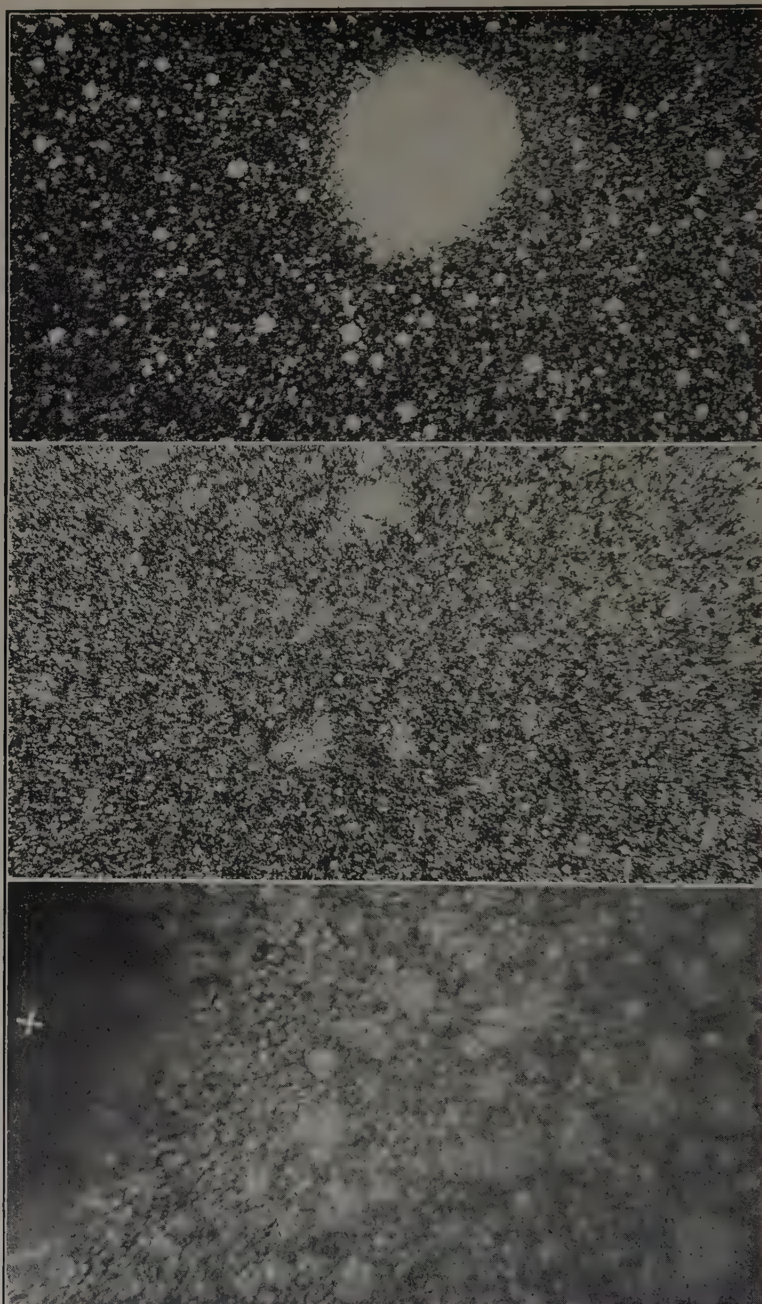


FIG. 21.—FIVE TYPES OF CELLS USED IN STUDYING CHARGE ON DISPERSED DROPLETS IN OIL-FIELD EMULSIONS.

Fig. 25 illustrates the migration of the water globules to the cathode. The voltage is not high. The circuit was disconnected after the short time indicated to avoid accelerating the globules, to diminish the breaking of the emulsion and to avoid the misleading rise of temperature. However, with the microscope one could follow the motion of the water globules towards the cathode. Fig. 26 is a different print of the same negative, taken to display the details not represented in Fig. 25. It was preferred to make two prints of the same plate rather than to reduce it. After many trials the platinum tips were adjusted far apart so that there was no disturbance of the migration. The passing current did not become noticeable at all. After this view was taken the circuit was connected again, and by the end of the first minute migration became turbulent and complete coalescence followed with a considerable current.



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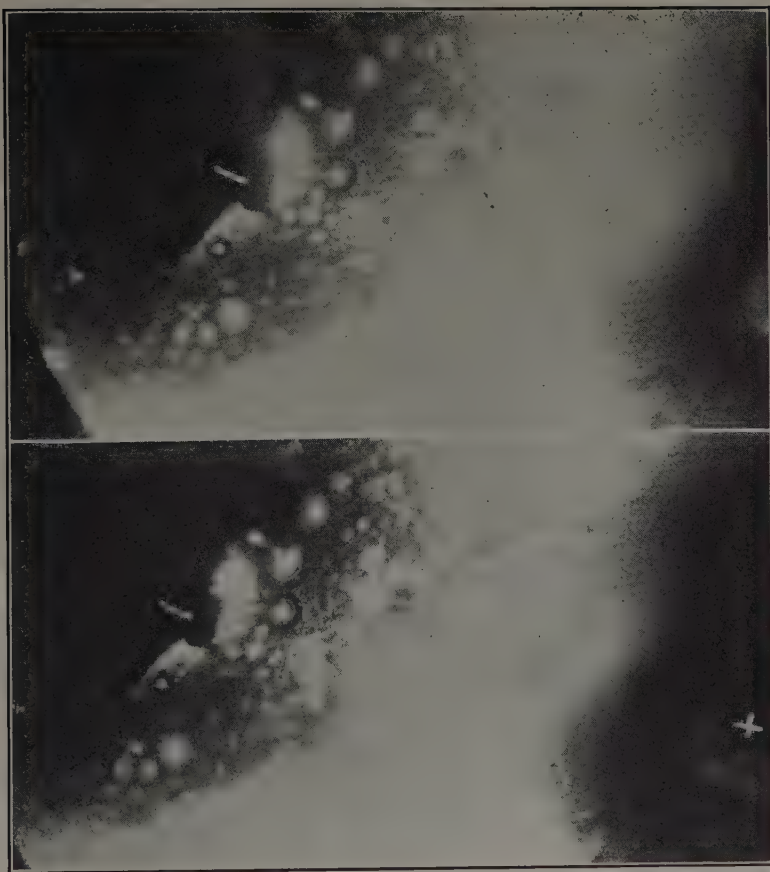
FIGS. 22–24.—SIGN OF CHARGE ON DISPERSED DROPLETS.
Captions on opposite page.



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FIGS. 25–26.—SIGN OF CHARGE ON DISPERSED DROPLETS. WATER DROPLETS ATTRACTED BY CATHODE. × 62.5.
Emulsion from Maricopa Flats.
Voltage, 22; time of test, 5 sec.

FIG. 22.—MIGRATION AWAY FROM ANODE. × 125.
Emulsion from Maricopa Flats.
Voltage, 3.1
Time of test, 24 hr.
Portion pictured, anode

FIG. 23.—MIGRATION TOWARDS CATHODE. × 125.
Emulsion from Maricopa Flats.
Voltage, 3.1
Time of test, 24 hr.
Portion pictured, cathode

FIG. 24.—BOTH ELECTRODES IN VIEW. × 125.
Emulsion from Huntington Beach.
Voltage, 6; time of test, 60 sec.

Fig. 27 is a lower magnification of Fig. 26 view. It took about two minutes to contract the camera bellows and to focus for this view, but

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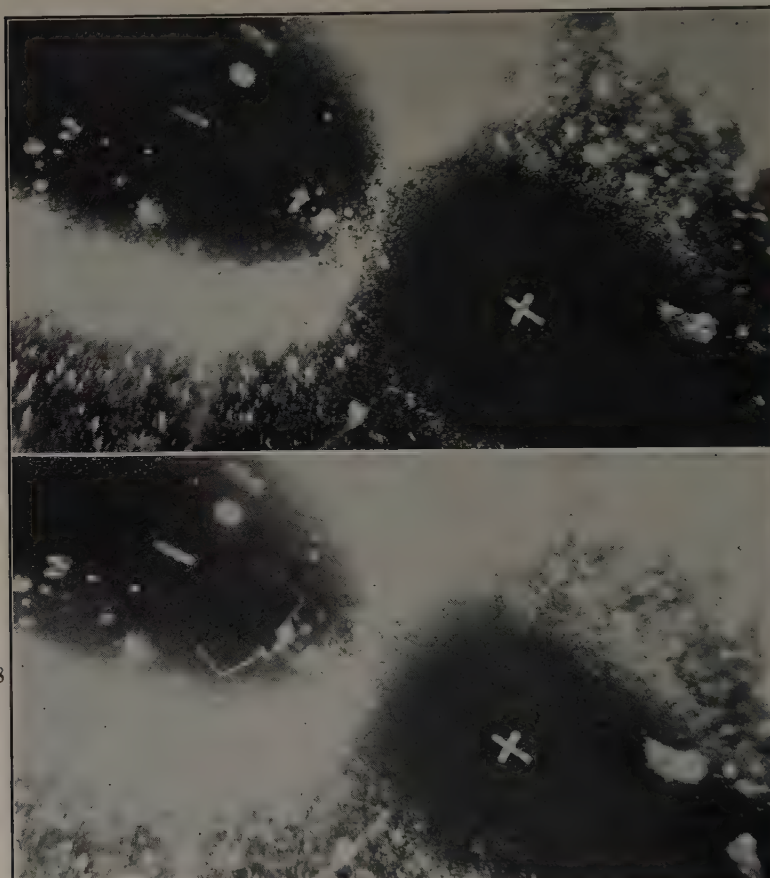


Figs. 27–28.—Sign of charge on dispersed droplets, water droplets attracted by cathode. × 25.

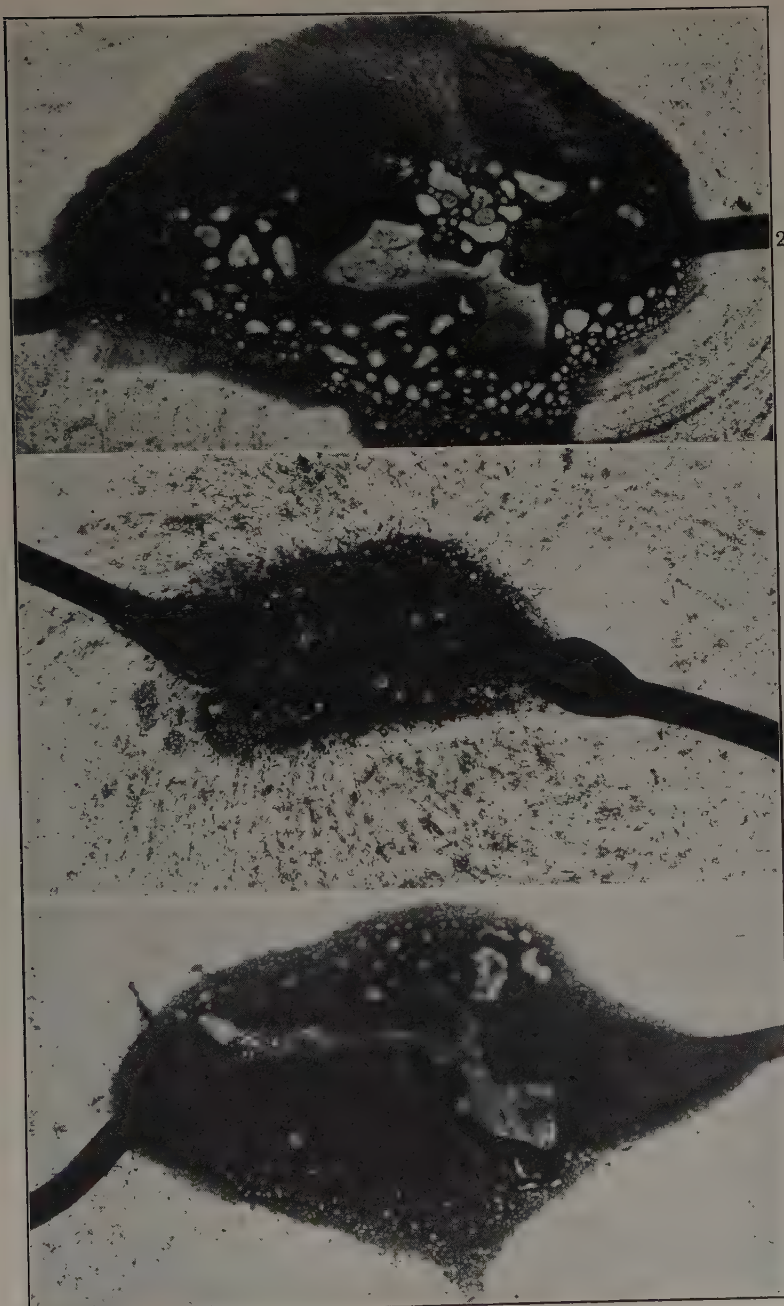
Same as Figs. 25 and 26 at lower magnification. In Fig 27 anode was completely immersed in oil. Fig 28 was retouched to show both electrodes.

there is no misleading difference between the original and the photographed fields.

Fig. 29.—Electrical treatment of Elk Hills emulsion. × 8.
Voltage, 110; time of test, 5 sec.

Fig. 30.—Electrical effects on Huntington Beach emulsion. × 13.5.
Voltage, 110; time of test, 2 sec.

Fig. 31.—Electrical effects on Huntington Beach emulsion. × 13.5.
Voltage, 110; time of test, 5 sec.



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Figs. 29–31.—Captions on opposite page.

Fig. 28 was retouched to show the location of both electrodes. The electrodes are immersed in cylindrical holes filled with mercury, described earlier in the paper.

High voltage, with copper electrodes, was tried to show whether any reversal of charge may occur. After several trials it was noticed that the water droplets coagulated very quickly. Even with a very wide gap, as indicated in Fig. 29, there was no sharp distinction as to the definite path which the globules take before they collide into one another. It is to be remembered that this emulsion is highly affected by heat. A longer duration of test or a narrower gap causes the oil to collect on the top and the water globules to come together, forming a layer of continuous electrolyte between the two electrodes.

Fig. 30 illustrates the form of water separation by a high voltage. When the slide was subjected to a temperature of 50° C. the emulsion was completely broken into two definite layers.

Fig. 31 was intended to show mainly the formation of a definite current path outside which the effect of the current is not as active. This fact suggests a necessity of moving the electrodes throughout the emulsion for an efficient electric method of breaking it.

Acknowledgments

Throughout this work the author was fortunate in having access to the facilities and technical instruments of the laboratories of both the Petroleum and the Chemistry Engineering Departments of the University of California.

Prof. L. C. Uren, of the Petroleum Engineering Department, and Dr. A. R. Olson, of the Chemistry Department, were very kind in the proffer of their advice and help, and it is with pleasure that the author acknowledges his indebtedness to them; also to Mr. M. W. Morris for performing the primary centrifuge tests of these emulsions.

Microscopic Study of California Oil-field Emulsions and Some Notes on the Effects of Superimposed Electrical Fields

By Harmon F. Fisher,* Los Angeles, Calif.

(Tulsa Meeting, October, 1930)

In the course of a comprehensive investigation for the development of the electrical process for the dehydration of oil-field emulsions, the writer has had an unusual opportunity to direct and execute a number of related, parallel studies concerning crude oil emulsions and extending over a period of nearly six years. Among these was an investigation utilizing the microscope for studying both the general characteristics of crude oil emulsions, the nature of their electrical charge and the action of an alternating current field in causing coalescence of the finely dispersed, more or less permanently suspended, emulsion particles into larger droplets of such mass that subsequent dehydration would follow by the ordinary process of settling, further agglomeration of the water droplets and, finally, separation into commercially dry, pipe line oil and a clean water discharge.

It is not the purpose of this paper to enter into a detailed discussion of the highly specialized subject of microscope technique, nor into a theoretical discussion concerning the origin of the electrical charge on the emulsion particle or concerning the mechanism of the electrical phenomena occurring during the electrical treatment of oil-field emulsions. In a short paper of this character one can hope to touch on only a very limited discussion of the theoretical aspects of crude oil emulsions. The subject of emulsions and colloids is comprised in a comparatively young science in which, however, very rapid progress is being made and consequently it is undergoing many changes; a tentative conclusion valid today may be overthrown tomorrow. Nor would it be a simple science even if it were no longer undergoing this rapid progress; a thorough study of emulsions is based upon a knowledge of such fundamental subjects as molecular structure, ionization and other electrical phenomena, surface chemistry, surface and interfacial tension phenomena, viscosity and other factors too numerous to discuss here and the fundamental theories of which are still undergoing more or less change. Therefore this paper will confine itself largely to a generally descriptive discussion, a sufficiently detailed outline of the microscope technique and a brief comment on

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adsorbed films at interfaces to enable others versed in the subject to form their own conclusions as to the basis for the statements contained herein.

Manner of Preparing Slide and Establishing Standard Conditions for Comparisons

In the laboratory with which the writer is associated, earlier efforts in microscopic examination were directed to eliminating effects due to the proximity of the slide and cover-glass surfaces by the use of slides having spherical recesses in which the emulsion was placed. On account of the opacity of most crude oil emulsions when viewed through any considerable thickness even with the strongest illumination, observation of necessity is limited more or less to the transparent, shallow, tapering rim of the droplet where it wets the slide, unless the emulsion happens to be a rather dilute one in a very clear, transparent oil. While it is true, theoretically, that the space distribution or packing of the emulsion particles and their freedom from restraint when freely dispersed in the sample droplet in the spherical recess, away from any surface effects due to the proximity of the slide and cover glass, more nearly approximates that existing when the emulsion is contained in larger bulk, nevertheless we deliberately have departed from microscope examinations under the above conditions and now have standardized on an examination of the emulsion confined in a comparatively thin layer between the slide and cover glass. There are several reasons for this decision:

1. In an open, exposed spherical recess without cover glass, the emulsion particles near the edge of the preparation are in continual violent motion or agitation, making observations extremely difficult. Air currents in proximity to the open preparation, the temperature effect due to the light used, and even that due to the temperature of the immediate surroundings and the natural evaporation at the exposed surface of the sample, all conspire to create disturbing effects which are difficult and even impossible to avoid with this type of preparation.

2. The focusing depth of field with the higher powered objectives is limited to an extremely thin plane of observation, so that with the preparation in a deep cell, such as in a spherical recess, a rather poor image may be obtained due to many moving particles above and below the one in the plane under observation. Even in the thin preparations used in our laboratory, the few particles above and below those under observation may affect the image somewhat.

3. With an open, exposed recess there is what appears to be an active coalescing action among emulsion particles going on at the edges of the test droplet when it is not protected by a cover glass and as a result the appearance of the emulsion is quite different here, appearing to be more dilute than within the bulk of the emulsion droplet.

4. The purpose of our microscopic investigations is principally for comparative purposes only and comparative observations are facilitated by a still preparation, particularly if we are making photomicrographic records; therefore a possible distortion of the space distribution or packing of the emulsion particles, provided it is comparable in all preparations, is not as important to us as the elimination of the first three sources of trouble listed above.

For our own photomicrographic and permanent record purposes we have found this method of having the cover glass resting directly on the emulsion to be satisfactory for the majority of emulsions coming to our attention. Our interest is largely in the fresh production emulsions which are generally fairly tight nowadays and in which we find the particle sizes[1] range from 0.2μ to 10μ. The larger particle sizes of 10μ may be distorted by contact with the cover glass and slide but this happens comparatively rarely and is usually evident by the appearance of the diffraction rings, or even by a distorted appearance of the droplet during inspection of the image or of the photomicrograph. In our thin preparations, the smaller particle sizes of 0.2μ to 5μ are usually quite free to move with the convection currents set up by thermal effects or by localized readjustment of pressure in some portion of the preparation between cover glass and slide or due to capillary leakage around the periphery of the cover glass. If the film is too thick for proper transparency, we apply external pressure on the cover glass until the desired thickness of film is obtained. The water particles in the emulsion have a decided tendency to wet the clean glass surfaces of the slide and cover glass, thus giving rise to an erroneous picture of the emulsion. To minimize this wetting of the glass surfaces we coat the under side of the cover glass and the surface of the slide with collodion, because the collodion film has a greater attraction for oil than for water. This gives a preparation in which the majority of emulsion particles are comparatively free from restraint or from wetting the glass surfaces.

Using the cover glass directly in contact with the emulsion and the slide below it, and with both surfaces collodionized, we rarely find the preparation to be changing rapidly, particularly on California emulsions. In fact, when about to take photomicrographs, we allow the preparation to "age" perhaps five minutes or longer to permit it to come to stable equilibrium, so that the minimum displacement of particles is likely to be encountered while making the exposure. In the majority of cases such slides show no noticeable change for many hours and remain almost permanent for days and even months when the oil is particularly viscous and the emulsion is finely divided.

The majority of our photomicrographs are made by using the usual small microscope lamp (4.8 watts) in conjunction with the ordinary Abbe

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[1] A micron (μ) is 0.001 mm., or about 1/25,400 inch.

condenser. For very finely divided emulsions, to obtain the best detail, we utilize the rays from an arc lamp passed through a water bath before reaching the substage condenser. For visual observation the arc lamp is hardly ever used unless the image is thrown on a transparent screen; for direct visual observation the arc lamp is very trying to the eyes and the ordinary microscope lamp with incandescent filament is best suited for this purpose. For very dilute emulsions, particularly if of very finely divided particles, we swing an opaque disk into place below the condenser, thus cutting off the direct rays through the condenser and illuminating the preparation with oblique rays. Crude oils containing less than 8 per cent. emulsion show up more distinctly by oblique illumination; above 16 per cent. emulsion content, direct illumination gives the better image.

Our experience with direct high magnification views has been disappointing. We seldom use magnifications higher than 103 on the microscope; with our photomicrographic arrangements this gives us a "picture magnification" of about 70 dia. We are now constructing a photographic attachment for taking direct photomicrographs with a picture magnification on the finished positive of about 150 diameters.

General Characteristics of California Emulsions as Viewed under the Microscope

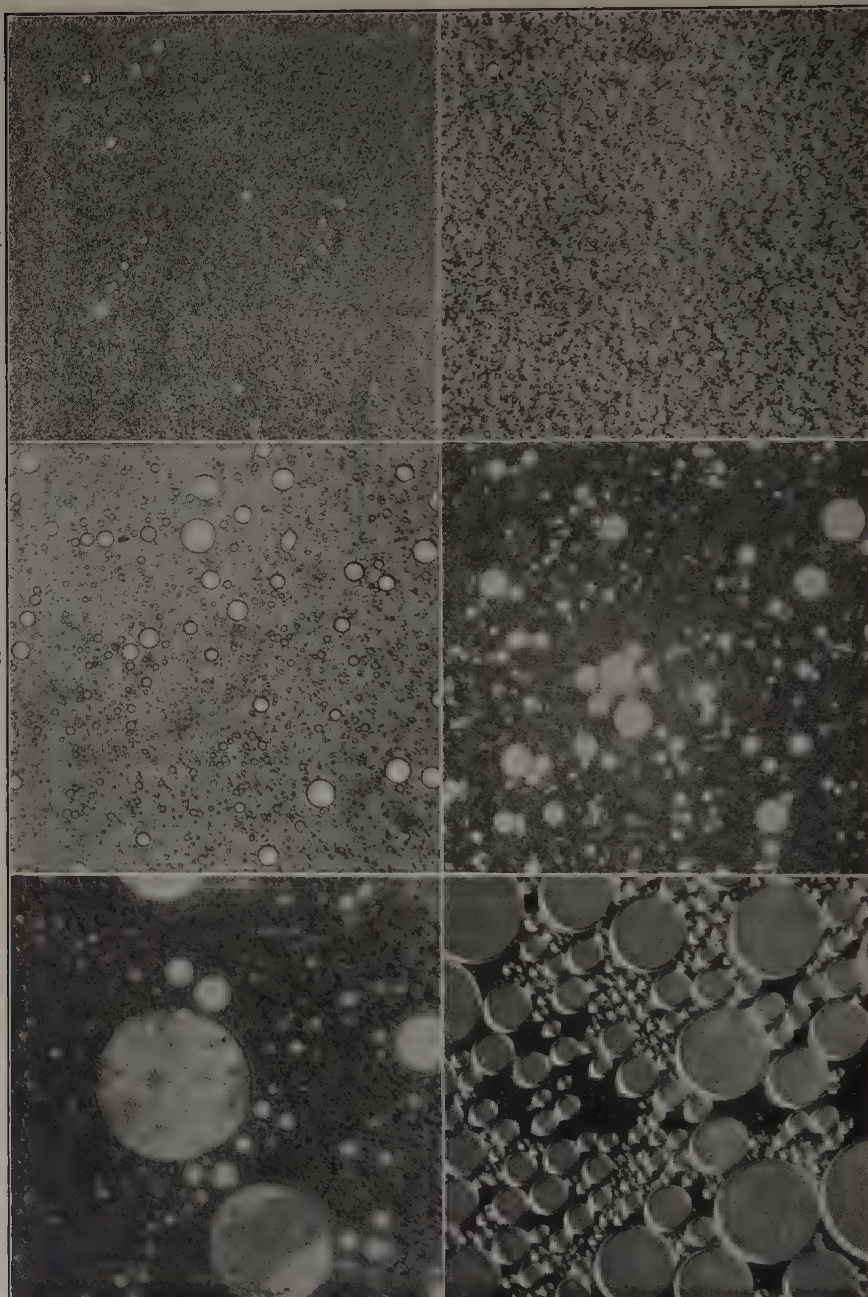
A word of caution is advisable as to the interpretations to be made of the microscope images. For the purpose of our special requirements, we have come to the conclusion that while the microscope, and particularly the photomicrographs made by its aid, are of great assistance in classifying emulsions and in determining some of their physical characteristics as determined by visual appearance, after all it is only an adjunct to other laboratory equipment upon whose findings we are more dependent in arriving at conclusions regarding the commercial dehydration of emulsions. Probably because we have the advantage of these other types of equipment, we have not tried to draw many conclusions from merely a microscopical study; we have, however, done some work to find out whether microscopical examinations can be substituted for tests in other equipment in our laboratory made on a larger scale and using larger volumes of emulsion to determine the behavior toward electrical treatment. While sufficiently encouraging results have been obtained to justify our belief that the use of the microscope might be extended by the development of a technique to permit estimating the behavior of an emulsion from the electrical dehydration standpoint, nevertheless the development of such a method will require considerably more time than we have been able to devote to it in the past, the biggest factor remaining to be determined being that of reliability in interpreting the

action presented to the eye. In the past, a great part of the time devoted to making microscopic examinations has been occupied in checking and rechecking our interpretation of what is presented to the eye, and we have been taught to be very cautious regarding our conclusions, particularly as regards polarity of charges.

The majority of California emulsions are of the water-in-oil type, but we do find a number of producing areas, a minor percentage, we grant, where the crude oil emulsions consist of a mixture of oil-in-water and water-in-oil emulsions. In such cases, after electrical dehydration of the emulsion has been effected, the separated water will contain a stable dispersion of oil particles, the smallest observed being about $\frac{1}{2}\mu$ and the predominating size being 3μ in diameter. Such oil-in-water emulsions have the appearance of weak coffee with milk added. The water containing this fine dispersion of oil particles frequently can be filtered through an ordinary chemical filter paper without materially affecting the appearance of the water. As a rule the waters from such emulsions are sweet to the taste. The California districts where such emulsions may be encountered are Olinda and areas of the San Joaquin Valley that produce the heavier oils.

One may find statements to the effect that the range of crude oil emulsion droplets varies from 10^{-4} to 0.2 mm. or from 0.1μ to 200μ and that those larger than 10μ are mechanically suspended, without a definition of the distinction between particles mechanically suspended versus true emulsion particles. Such a distinction is more or less a forced one. Possibly there may be reference to the behavior of the crude oil when centrifuged; after a certain amount of centrifuging the larger particles may be found to have been coalesced by the increased mechanical forces and in reporting a centrifuge "cut," such centrifuged water may be reported as "free water." Left in field storage tanks, such particles perhaps may settle out on very prolonged standing. There are so many factors to consider, such as the temperature-viscosity characteristics of the oil and particularly the interfacial tension between the water and oil which might be effective in causing a particle of a given size to remain permanently suspended in one oil, whereas the same particle suspended in another oil might settle out rapidly and coalesce when it reached the water or sludge layer in the bottom of the tank, because of lower viscosity or higher interfacial tension characteristics in the changed environment.

The range of particle sizes as quoted above is inclusive for the smaller sizes but may not go quite far enough in the other direction. However, our method of preparation usually will cause distortion of particles larger than 20μ and we are not prepared to set an approximate limit to these larger sizes. With the ordinary light sources and with a microscope using optical glass lenses, slides and condenser, the lower limit of resolving



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FIGS. 1 TO 6.—CALIFORNIA EMULSIONS. FRESH PRODUCTION. DESCRIPTIONS ON OPPOSITE PAGE.

power will be about 0.2μ to 0.5μ. The lower limit of particle sizes mentioned above is smaller than half the wave length of the shortest wave lengths transmitted by glass; to produce a distinct image with the highest magnification the particle sizes must not be smaller than one-half the wave length of the light used. In the course of our experience, we have found that the majority of the "deep-sand" or "gas-blown" crude oil emulsion particle sizes range from 0.5μ to 10μ. Upper sand emulsions or pumping well emulsions are generally coarser, ranging from 5μ to 100μ and larger. Emulsions having particles ranging from 5μ to 100μ or larger are termed "loose" emulsions in our laboratory studies.

We have noted sodium chloride crystals in but a few California emulsions under special conditions and we question their presence in a majority of emulsions. We are forced to believe that the crystals observed by others may have been due to adsorption or evaporation of water from the emulsion particle, and this is the more probable when we consider the method sometimes used of preparing the slide by flowing the emulsion over the surface by gravity. Contact with a clean, dry glass surface and exposure to the air may account for the adsorption or evapo-

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FIG. 1.—HUNTINGTON BEACH, CALIF. × 70. GRAVITY 14.5° A. P. I. CUT: SEDIMENT, 0.3; WATER 5.8; EMULSION, 8.2; TOTAL, 14.3 PER CENT.

Oil from a pumping well. The appearance of this photomicrograph as representing emulsion from a pumping well is somewhat unusual because of the fineness of the dispersion; an emulsion of this texture is usually associated with a gas-blown or a flowing deep-sand well. A few particles of 10μ to 20μ dia. are visible; the majority are 5.0μ dia. or less.

FIG. 2.—ELWOOD, CALIF. × 70. GRAVITY 34.5° A. P. I. CUT: WATER, 0.2; EMULSION, 13.4; TOTAL, 13.6 PER CENT.

Crude oil from a typical flowing well. A few particles of 10 to 20μ are visible; the smaller sizes average about 5μ and range on down to 1μ or even smaller.

FIG. 3.—MONTEBELLO, CALIF. × 70. GRAVITY 18.6° A. P. I. CUT: WATER, 28.0; EMULSION, 3.0; TOTAL, 31.0 PER CENT.

Typical emulsified oil from a pumping well. The larger particles are probably 30 to 40μ in diameter; the smaller average about 5μ and range down to 1μ or less.

FIG. 4.—VENICE, CALIF. × 70. GRAVITY 21.2° A. P. I. CUT: EMULSION, 51.0; TOTAL, 51.0 PER CENT.

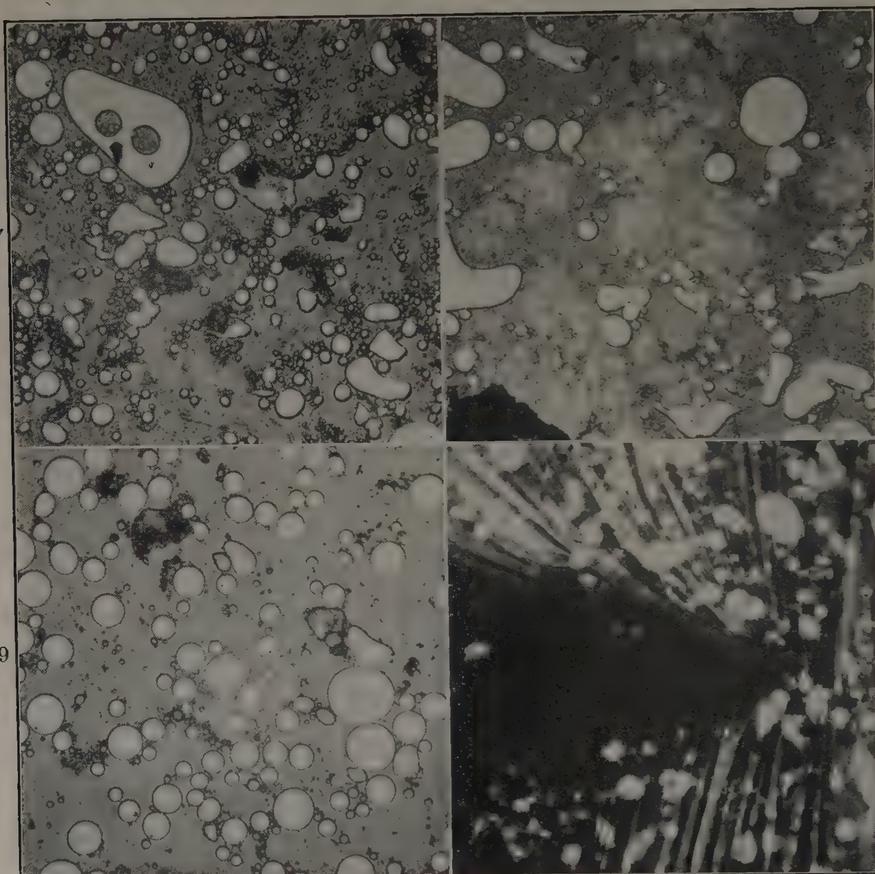
Rather dense preparation having a total cut of 51 per cent. of emulsion from a flowing well. The larger particles are probably 30 to 40μ in diameter; there is a scattering of particles 10 to 20μ dia. and the bulk of the emulsion appears to be 2.5μ dia. or smaller.

FIG. 5.—BREA, CALIF. × 303. GRAVITY 19.6° A. P. I. CUT: WATER, 16.0; EMULSION, 34.0; TOTAL, 50.0 PER CENT.

Double emulsion of oil particles in water droplets, the water droplets in turn being dispersed in the larger oil bulk. Typical emulsion from Brea district. The larger oil-in-water particles average about 2μ dia. and the smaller about 1μ or less. The larger water particles are about 40 or 50μ dia.; a number average about 2 to 5μ and a few range on down to 1μ or less.

FIG. 6.—SEAL BEACH, CALIF. × 70. GRAVITY 24.7° A. P. I. CUT: WATER, 24.0; EMULSION, 40.0; TOTAL, 64.0 PER CENT.

Rather coarse emulsion from a pumping well. Indirect illumination. The larger droplets are distorted from a spherical form and probably are 100μ dia. or larger when not distorted. There are many smaller particles averaging 10μ to 20μ dia. and a very few particles of 10μ or less.



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FIGS. 7 TO 10.—CALIFORNIA EMULSIONS. TANK BOTTOMS AND SUMP OILS.

FIG. 7.—TORRANCE, CALIF. TANK BOTTOMS. × 70. CUT: SEDIMENT, 26.0; WATER, 40.0; EMULSION, 14.0; TOTAL, 80.0 PER CENT.

FIG. 8.—TORRANCE, CALIF. TANK BOTTOMS. × 70. CUT: SEDIMENT, 0.1; WATER, 1.0; EMULSION, 86.9; TOTAL, 88.0 PER CENT.

FIG. 9.—SIGNAL HILL, CALIF. SUMP OIL. × 70. CUT: SEDIMENT, 0.4; WATER, 19.6; EMULSION, 22.0; TOTAL, 42.0 PER CENT.

FIG. 10.—SIGNAL HILL, CALIF. SUMP OIL. × 70. CUT: SEDIMENT, 10.0; WATER, 70.0; TOTAL, 80.0 PER CENT.

Usually these tank bottom accumulations show very low interfacial tensions between oil and water and this is also evidenced by the ragged, indefinite shape of the water droplets in Figs. 7 and 8. Existence of a coagulated, adsorbed membrane or "skin" which collects at the interface between oil and water is very evident in the unusual photomicrograph shown in Fig. 10. Close examination of Figs. 7 and 8 also shows slight evidence of the existence of such coagulated membranes. All show evidence of the presence of colloidal solids.

ration of the water from the particles, thereby leaving salt crystals behind. This action is surprisingly rapid when a very thin film of oil is spread over a clean dry glass surface and we have noted salt crystals shortly after making a preparation in this manner. However, in thousands of observations made in our laboratory on slides prepared so as to avoid the action described, finding salt crystals in California emulsion water is rare. On the other hand, salt crystals frequently are found in the emulsion droplets of crude oil emulsions from West Texas, the Texas Panhandle and Oklahoma.

It is probably true that most California emulsions contain colloidal suspensions of organic matter; but these may be in such fine colloidal dispersion as to be invisible through the microscope, unless precipitated or coagulated by petroleum ether. It is believed that it is largely the presence of these organic compounds, particularly the asphaltenes, that gives to some California emulsions their great stability. Large quantities of colloidally suspended inorganic matter are found in emulsions produced from new wells which have not freed themselves from drilling mud; or in emulsions from wells adjacent to others that are being drilled and where some infiltration of drilling mud is taking place. Sump oils and tank bottoms almost invariably show varying amounts of suspended colloidal and even larger particles of inorganic matter.

The interface between water and oil is a region in which molecular forces are active and where adsorption of colloidal substances through molecular distances is taking place. The existence of such adsorbed films of colloidal material may be demonstrated, after the resolution of the emulsion, which causes contraction of the interface between the accumulated water and the dry oil and the consequent coagulation of a sufficient quantity of adsorbed colloidal matter which in its more concentrated condition may form a fairly thick skin having considerable tensile strength. Such demonstrations often can be made after resolving or "breaking" sump oil emulsions which had been exposed to air and where in consequence oxidation has taken place. Such a coagulated "film," however, is a vast number of molecules thick and might be better termed a "skin." However, even such a concentrated "film" of coagulated adsorbed colloidal material is usually so thin that it is quite transparent and it is only by distorting the "film," or "skin," in such a way as to permit a portion of the skin to be folded over itself that indications of its presence in a microscope preparation become plainly evident. Even then, indirect or oblique illumination may have to be used to make the skin visible. In crude oil emulsions, true films of adsorbed material, as we regard them, are of the order of one molecule in thickness and evidence of their presence is extremely difficult to detect in the majority of fresh emulsions except by indirect methods. Sump oils and tank bottoms, as mentioned before, will show evidence of the presence of such skins.

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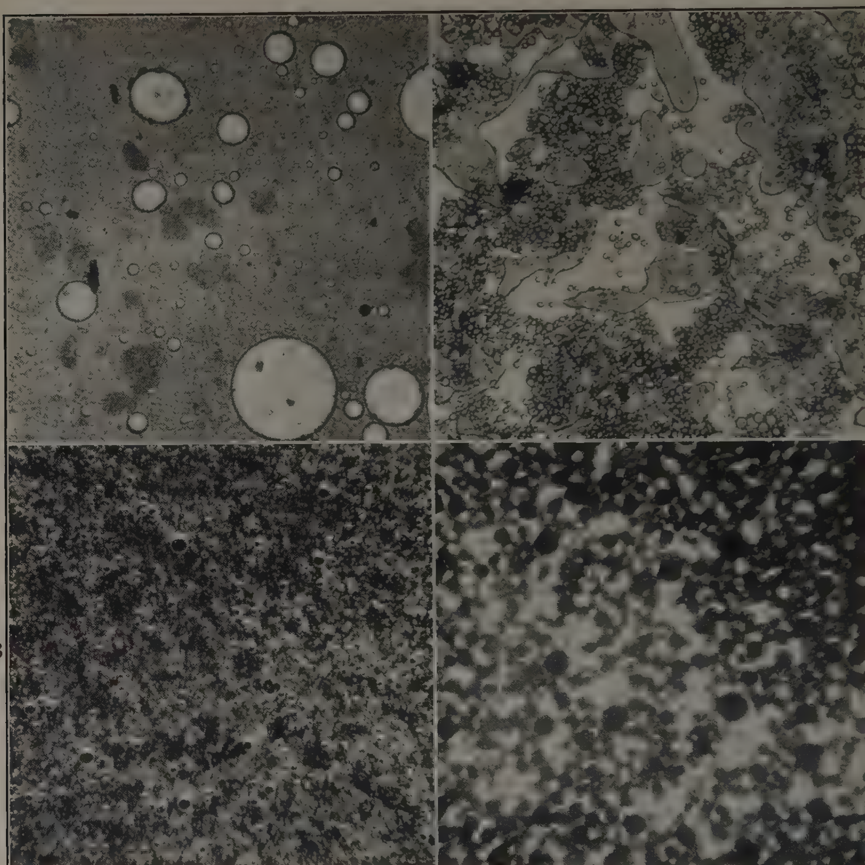


FIGS. 11 TO 14.—MISCELLANEOUS EMULSIONS.

FIG. 11.—MUSKEGON, MICH. × 70. GRAVITY 39.0° A. P. I. CUT: SEDIMENT, 0.5; WATER, 7.0; EMULSION, 8.5; TOTAL, 16.0 PER CENT.

This contains dispersed particles of amorphous paraffin together with other suspended solids, as indicated by the black particles.

FIG. 12.—REMARKABLE EXAMPLE OF A DOUBLE EMULSION. SALT CREEK, WYO. × 70. CUT: SEDIMENT, 2.4; WATER, 35.1; EMULSION, 36.0; TOTAL, 73.5 PER CENT.

The oil particles dispersed in the water average about 5 to 15μ in size although some smaller oil-in-water particles down to about 1μ are visible. The dispersion of water-in-oil shows particles of about 10μ. In general, the bulk of this mixture of water and oil is very "loose" and coarse.

FIG. 13.—OKLAHOMA EMULSION BY INDIRECT ILLUMINATION. LOVELL, OKLA. × 70. GRAVITY 39.7° A. P. I. CUT: WATER, 12.0; EMULSION, 5.0; TOTAL, 17.0 PER CENT.

This is a finer grained dispersion than is usually found for emulsions from the Mid-Continent; generally they appear to be much coarser, resembling in appearance the Seal Beach emulsion shown in Fig. 6. The average particle size here varies from often 20μ to an average of about 5μ to 10μ and grades down smaller to about 1μ.

FIG. 14.—INTERESTING EXAMPLE OF OIL-IN-WATER EMULSION OBTAINED FROM SMACKOVER, ARKANSAS. × 70. CUT: WATER, 35.0; TOTAL, 35.0 PER CENT.

The larger oil particles are about 20 to 40μ dia. and average between 10μ and 20μ. Very few oil particles smaller than 10μ are visible in this photomicrograph.

FIG. 15.—MOTION PICTURE STUDY OF SIGNAL HILL EMULSION PARTICLE MIGRATION IN SHALLOW CATAPHORESIS CELL SPECIALLY CONSTRUCTED FOR PHOTOGRAPHIC RECORDS.

The gap between parallel-edged electrodes is 0.7 mm. and the thickness of the preparation is about 50μ. About 40 volts from a battery of dry cells is steadily applied to the cell and within a few minutes the migration has proceeded far enough to indicate the polarity of the dispersed particles. The time interval between views is 1 sec. For check purposes when definitely establishing the polarity, a cataphoresis cell is used based on the type illustrated by Svedberg (*Op. cit.*, 233).

Depending upon the character of the colloid, such skins, particularly if of solid emulsifying agents, may become fairly thick and slightly opaque, particularly at a very oblique angle. A distinction should be borne in mind between an adsorbed film of molecular thickness and coagulated heavy layers of solid colloids that are visible under the microscope. Such layers of coagulated colloidal solids may require considerable mechanical force to distort them, and this fact, aside from very low interfacial tensions, undoubtedly accounts for much of the difficulty encountered in the dehydration of emulsions associated with sump oils and tank bottoms.

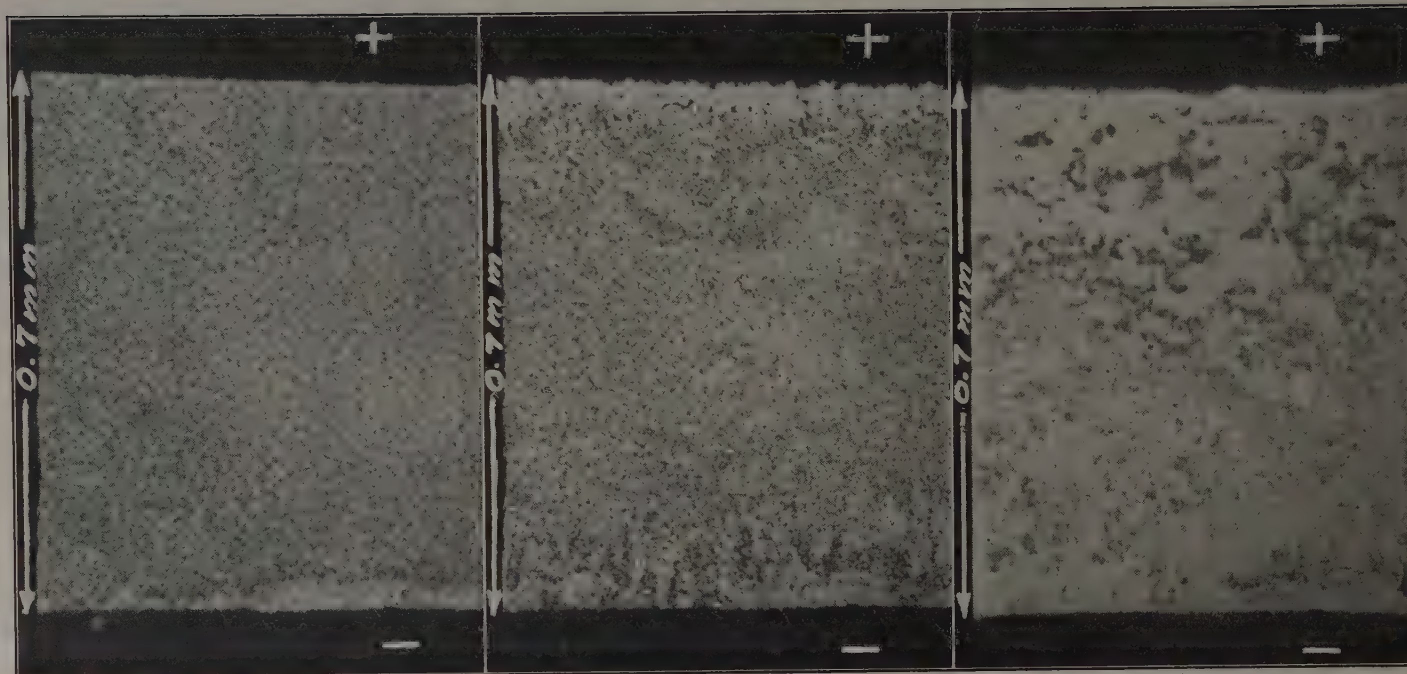
Heat Effects on Emulsions as Viewed under the Microscope

It is difficult to give an adequate conception by means of isolated still photomicrographs of the motion of the emulsion particles caused by thermal effects. A motion picture study of these movements would be necessary to describe them clearly.

In our laboratory work we have noted such thermal convection currents and have been interested more in means for avoiding them under the microscope than in observing them. We know by experience that heat alone will not provide commercial dehydration of the California emulsions and for that reason we have not devoted much time to this angle of the microscopical studies.

Casmalia crude oil is one of the most viscous, heavy-gravity emulsions to be found anywhere and in all probability it is one that is best adapted to show the increasing activity of the thermal convection currents with rising temperatures. The lively spinning and colliding of emulsion particles, particularly at the boundaries of the thermal convection currents, is a normal occurrence and will be noted with almost all emulsions when allowed to warm up locally. The bubbles sometimes observed and described as "air" bubbles are very likely gas bubbles, since all fresh crude oil samples will show evidence of its presence when first heated under the microscope.

Gas bubbles coalesce readily and with great rapidity. The similar coalescence of emulsion particles in this manner by moderate heat only, without actual evaporation of the water, is not typical of most California emulsions, particularly of the very tight deep-sand production or gas-blown emulsions encountered nowadays. We have, however, found a very few of the heavy-bodied wet crudes in the northern producing areas, particularly Coalinga, which do show some tendency to respond to heat dehydration alone. In the majority of other cases, the product resulting from heat dehydration only does not meet rigorous pipe line requirements within reasonable cost.



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FIGS. 16–18.—ENLARGED PHOTOMICROGRAPHS OF CATAPHORESIS MOTION PICTURE STUDY SHOWING ACCUMULATION OF NEGATIVELY CHARGED EMULSION PARTICLES AGAINST POSITIVE ELECTRODE AND LACK OF ACCUMULATION AGAINST NEGATIVE ELECTRODE.

Refer to Fig. 15 for establishing sequence of above views and for comparing appearance of the enlarged view with small-sized view.

FIG. 16.—TWO SECONDS BEFORE START. FIG. 17.—FIVE SECONDS AFTER START. FIG. 18.—ONE HUNDRED FIFTY-FOURTH SECOND AFTER START.

Often the appearance is noted of a large water particle acting as a nucleus around which smaller ones agglomerate and into which they may coalesce; this is typical particularly of the heavy-bodied, viscous crude oils. In such emulsions some beautiful, striking examples have been noted of an almost geometrically arranged, very regular, uniform gradation in size of particles ranging from that of the large nucleus at the center to the smallest almost invisible particles at the outer rim, arranged in concentric circles having a maximum radius for the outer circle equal to perhaps a full diameter of the larger inner particle.

Dilution Effects on Emulsions

With the exception of emulsions from a few districts, among which we may list some easily broken emulsions from Maricopa Flats, dilution with light petroleum products shows no appreciable resolving effects on California emulsions. On a number of occasions we have "washed" stable California emulsions by repeated dilution both with gasoline and benzol, followed by centrifuging, to separate the two phases until the appearance of the concentrated emulsion particles in the centrifuge tube was of a light cream or ivory color as contrasted with the usual dark brown or tan appearance of the dispersed phase, and this relatively rough treatment did not result in any appreciable degree of resolution or breaking of emulsion. The dark appearance resulting from a preliminary "washing" with light petroleum products and subsequent dissolving of this black surface layer when followed by a benzol "wash" probably indicates the presence of asphaltenes. Evidently the oriented molecular (or adsorbed colloidal) films at the interfaces between the dispersed water and oil phases in California crude oil emulsions possess considerable stability.

Electrical Effects on California Oil Field Emulsions as Viewed under the Microscope

In our work cataphoresis cells of the capillary or U-tube type have given conflicting evidence as to the electrical charges, and the results have not been easily interpreted. We have had better success with closed microscope cells of the type of construction shown and discussed by Svedberg,[2] and greatly prefer to work with them. Our various cells have a depth of 0.076 to 0.152 mm. and a gap between electrodes of about 0.17 to 0.3 mm. The applied voltage is of the order of $1\frac{1}{2}$ to 75 volts direct current.

It is possible that the oil may be so viscous or the particle may be so large or may have such a low charge that very little motion is discernible under the influence of an electric field, but we believe that almost

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[2] T. S. Svedberg: Colloid Chemistry, Ed. 2, 233, Fig. 132, 1928. Chemical Catalogue Co., New York.

FIG. 19.—ELECTRICAL TREATING TEST ON MARICOPA EMULSION (500 VOLTS, 50 CYCLE ALTERNATING CURRENT).

invariably a definite electrical charge will be associated with the dispersed particles of a stable California emulsion, and in every one of the tests made on these emulsions this charge has been found to be negative.

In the cataphoresis cell, emulsion particles apparently act as electrical carriers by seemingly picking up a charge and then being repelled from a continuous polarity electrode after having previously been attracted to it, but we believe it would be erroneous to assume that the mechanism of the action which provides such reversal of charges can be regarded as an adequate explanation of the phenomena which are effective in the resolution of the emulsion by the electrical process on a commercial scale.

The accompanying photomicrographs are typical of those made on California emulsions obtained from fresh production, tank bottoms and sump oils. The tank bottoms and sump oil show the presence of considerable suspended solid matter. A typical "skin" or "film" of coagulated colloidal material is clearly evident in one of these photomicrographs.

Motion picture photomicrographs showing the migration of dispersed California emulsion particles between the electrodes of a cataphoresis cell (Figs. 15 to 18) and others showing the progressive treating action when using an alternating current field in a special cell devised for this purpose at our laboratory (Fig. 19) are included.

One's first impression from a casual examination of Fig. 15 would be that the migration is toward the cathode (marked as the negative electrode). However, visual observation under the microscope, as well as a close examination of the enlargements shown in Figs. 16, 17 and 18 show that no accumulation of particles is taking place against the cathode. This electrode (marked −) after the 154th second is as free from emulsion particle accumulation as at the beginning of the test. On the other hand, observation under the microscope, as well as a close examination of the enlargements, definitely shows a pronounced accumulation on the edge and surface of the anode (marked as the positive electrode), thus showing these particles to be negatively charged. The cover glass in the specially modified cell does not rest directly on top of the electrodes and thus permits some freedom of action in that region. Consequently some of the emulsion particles have migrated beyond the outlined edge of the electrode and no longer are visible in the photographs.

In this connection it is well to point out that these migration studies are best made with emulsions that do not coalesce too rapidly under the influence of the low voltages applied to these cells.

Fig. 19 shows a photomicrograph study of a section of the alternating current field between concentric electrodes under the microscope. These views are taken at a standard speed of 16 exposures per second. In less than 16 sec. the treating action is practically complete. At the beginning of the strip, the field of vision is dark because of the opacity of the fine dispersion of emulsion particles. Some coalescence is visible adja-

cent to the electrodes, immediately after the switch is closed and within the first half second a decided coalescence and consequent cleaning-up of the field is visible. About halfway through the study—between 7½ and 8 sec.—very few finely dispersed emulsion particles are visible and instead there appear a few larger droplets of accumulated water and a few bubbles of gas. Toward the close of the 15 to 15½-second section of the strip, the field of vision is practically clear and transparent except in the lower right-hand corner, where a few finely dispersed water particles still persist. A few more larger gas bubbles are also visible. From the very start, a tendency of the water particles to line up in the direction of the radial field is noticeable; likewise their tendency to become elongated. No such tendencies are apparent in the darker rimmed gas bubbles.

Acknowledgments

I wish to acknowledge my indebtedness to Mr. I. LaVell Cooley who has obtained and prepared the striking photomicrographs accompanying this paper. I am indebted also to Messrs. Wm. Woelflin and R. L. Pettefer, also of our organization, who have been of the greatest help in obtaining the original data.

Chapter IV. Production

Petroleum Production, 1930

By D. R. Snow,* Tulsa, Okla.

(New York Meeting, February, 1931)

The year 1930 stands out in the petroleum industry as an exceptional one in many ways. It is one of the few years in its history during which crude oil production declined from that of the previous year in nearly every important producing district in the United States and in the world as a whole. World production of crude oil declined approximately 81,000,000 bbl., from 1,484,451,000 bbl. in 1929 to 1,403,500,000 bbl. in 1930. Production of crude oil in the United States declined approximately 111,000,000 bbl., from 1,007,323,000 bbl. in 1929 to a production of 896,265,000 bbl. in 1930. World production outside of the United States increased approximately 30,000,000 bbl., due principally to the increased production in Russia. This, together with the decided decrease of production in the United States, resulted in a smaller percentage of world production in the United States than in any other year since 1921. This declining production occurred in the face of the greatest visible supply in the form of potential production that the industry has ever known and was clearly the result of the great efforts put forward to restrict production, both by proration and by unitization. Throughout the year, developments along the lines of proration and unitization have overshadowed all other developments in the minds of those interested in the oil industry and will, no doubt, continue to do so more and more in the future, as it is quite evident that the industry cannot hope to maintain itself in a profitable position, without some rational plan of bringing about a better balance between supply and demand than has existed in the past.

The successful operation of the Van field unitization agreement and the recently completed Kettleman Hills plan are indicative of what may be expected in the future along this line. That real progress has been made in this direction is shown by the fact that total crude oil stocks in the United States were decreased by approximately 28,000,000 bbl. during the year 1930. This is the only year on record during which such a decrease of crude oil stocks was accompanied by a severely declining price structure. This reduction of crude stocks is apparently continuing even after the price has reached its present low level, indicating that there is no

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fear of an oil shortage in the near future and emphasizing the fact that potential production for the United States, and of the world as a whole, together with developments indicating new prolific fields as yet undeveloped, is such that many leaders of the industry are willing to admit that overproduction has changed from an apparent temporary condition to a permanent one, and that the development of methods of production control is more important than the discovery of new fields.

The papers that follow cover the detailed production developments in the various districts of the United States and in foreign countries. A discussion of these developments is, therefore, omitted here.

Oil and Gas Production in the Eastern District during 1930

By J. French Robinson,* Pittsburgh, Pa.

(New York Meeting, February, 1931)

A review of production in the Eastern District for 1930 is necessarily brief. Drilling operations were curtailed, due to economic conditions, which in turn reduced production. However, in spite of these conditions, there have been a few outstanding developments which surpass any of recent years.

The development of a field in Chautauqua and Cattaraugus counties, New York, has been rapid and probably reached its peak of production in 1930. The gas in this field comes from the White Medina Sand (Silurian), at an average depth of 2600 ft. Some of the wells had an open flow of 20,000,000 cu. ft. of gas per day,[1] with an original rock pressure of 965 pounds[2] per square inch.

Another area developed during 1930 was the Tyrone field, in Tyrone Township, Schuyler County, New York. This field was discovered and is practically controlled by the Belmont Quadrangle Drilling Corpn. of New York. The production is from the Oriskany Sand (Devonian), which is found at an average depth of 2100 ft. The field covers approximately 2000 acres, and to date has 14 producing gas wells. The largest well had an open flow of 15,000,000 cu. ft. and an original rock pressure of 740 lb. The gas from this field is impregnated with sulfur, and requires washing before it is marketed.

Because little is known of the Oriskany Sand, a brief description may be of interest. This sand outcrops at Oriskany Falls, New York, and has a thickness of 10 to 12 ft. Its texture is coarse grained, it is composed mostly of quartz and is a regularly bedded sandstone. At Yauger's Wood, in Cayuga County, New York, it is exposed and shows a thickness of 26 feet.

The discovery of the Tyrone field led to much prospecting in the New York and the northern part of Pennsylvania, and as a result of this search, the Allegany Gas Co. struck a large gas well in Farmington Township, Tioga County, Pennsylvania, which created considerable excitement through the Eastern District. The gas was encountered at a depth of 4010 ft., and tested 20,000,000 cu. ft. open flow, with a shut-in pressure

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[1] Through this paper, gas quantities are per day.

[2] Through this paper, rock pressure is in pounds per square inch.

of 1750 lb. It is generally supposed that the producing horizon is the Oriskany but this has not been definitely determined. Twenty or more of the larger companies, besides many independent operators, are planning development in this field. Approximately 25 interesting tests are under way now, the results of which will be eagerly watched.

Considerable drilling has been done in Clearfield County, Pennsylvania, during the year 1930, with varied results. Several dry holes have been drilled near two good gas wells. The wells produced from the Sheffield Sand, and had an open flow of approximately 2,000,000 cu. ft. each.

An interesting development in 1930 was the completion of a 750,000 cu. ft. gas well in Quemahoning Township, Somerset County, Pennsylvania. The gas was struck at a depth of 2400 ft., and had a rock pressure of 800 lb. This well is of especial interest because it is near the eastern limit of gas production, in commercial quantities, within Pennsylvania.

Probably the most unusual development in West Virginia, during 1930, was the striking of gas in Monroe County. However, the production from this county to date does not warrant an extensive drilling campaign. Three wells have been drilled, resulting in two producers and one dry hole. The fourth well is drilling. This production also marks a new eastern limit for commercial production in the gas industry.

Another unusual development in the Eastern District is that of the Horse Cave field in Hart County, Kentucky, where a 10,000,000-cu. ft. well was struck at a depth of 316 ft. This gas was found in a formation called the Black Lime. Approximately 50 wells are drilling in this locality at the present time.

This covers the most outstanding developments in the Eastern District, but there have been several unusually large wells obtained in old fields and extensions of old fields, which are very interesting. The most important developments in the Eastern District during 1930 are reported below.

Outline of Development and Production

New York State

In New York there were two new fields of interest—the Nashville and the Tyrone.

The Nashville field of Chautauqua and Cataraugus counties was under way in 1929, but reached its peak of production in 1930. This is from the Medina Sand (Silurian), at an average depth of 2600 ft. Some of the wells had an open flow of 20,000,000 cu. ft. and an original rock pressure of 965 pounds.

The Tyrone field, discovered and practically controlled by the Belmont Quadrangle Drilling Corpn. of New York, is in Tyrone Township, Schuyler County, New York. The production in this field is from the

Oriskany Sand at an average depth of 2100 ft. The discovery well was located on a definitely defined structure, and was completed Feb. 28, 1930. To date, 14 gas wells have been completed in this field. The largest well had an open flow of 15,000,000 cu. ft., with an original rock pressure of 740 lb. The productive field at present covers about 2000 acres, but it is quite possible that this may be extended until it covers 6000 acres. The limits of the field have been fairly well established in certain directions, as the following will indicate: There have been two dry holes drilled about ¾ mile north of the field, one dry hole 2½ miles south of the field, one dry hole 5 miles east of the field, and seven holes off to the southwest of the field. Just recently, a well was completed 2½ miles west of the field, which had an open flow of 750,000 cubic feet.

The gas from this field is impregnated with sulfur, and must be washed before marketing. The gas from the last mentioned well, which is 2½ miles west of the main field, is sweet and does not require washing. It is thought by some that this gas is from a higher horizon than the gas in the main field. All of the mentioned gas is being used for local markets.

Following the development of the Tyrone field, many wells have been drilled and many are now drilling in south-central New York. Several of these wells have passed through the Oriskany Sand horizon and found it either missing or dry. Some of the wells have been drilled to and through the Medina horizon. Several important tests throughout the southern part of New York should reach the Oriskany Sand horizon within the next two or three months.

Pennsylvania

In Pennsylvania there were three new developments of interest in Tioga, Clearfield and Somerset counties.

The discovery of the Tyrone field lead to much prospecting, which reached into Pennsylvania and resulted in the Allegany Gas Co. drilling in a large well on the Palmer farm, in Farmington Township, Tioga County, Pennsylvania. This well encountered gas at a depth of 4010 ft., and had an open flow of 20,000,000 cu. ft. The shut-in pressure was 1750 lb. It is generally supposed that the producing horizon is the Oriskany, but this has not been definitely determined. The gas is sweet and is being used locally. It is needless to say that an extensive leasing campaign has been under way in southern New York and northern Pennsylvania, with practically all available territory being under lease.

In Clearfield County, considerable drilling has been done during 1930, with varied results. Two gas wells are producing from the Sheffield Sand with an approximate open flow of 2,000,000 cu. ft. each. Several dry holes have been drilled nearby.

In Quemahoning Township, Somerset County, a well was drilled in with an open flow of 750,000 cu. ft., and an original rock pressure of 800

lb. Since the completion of this well, two dry holes have been drilled in this vicinity.

These developments are of unusual interest, because they are beyond what has always been recognized as the eastern limit of commercial gas fields in Pennsylvania.

The deep well which was completed by the Peoples Natural Gas Co. in 1918 is now flowing large quantities of salt water, and will soon be abandoned. This well was located on the Chestnut Ridge Anticline, near Ligonier, and was producing gas from the Oriskany sand, at a depth of 6822 ft. The failure of this well does not lend much encouragement to deep sand development in southwestern Pennsylvania.

Following is a list of other unusual developments in Pennsylvania during the year 1930:

Allegheny County.—Robinson Township: A 30-bbl. oil well was encountered from the Gordon Sand. Sewickley Heights Township: 2,800,000 cu. ft. of gas from the Thirty Foot Sand. Upper St. Clair Township: 1,500,000 cu. ft. of gas from the Salt Sand.

Armstrong County.—Mahoning Township: 8,500,000 cu. ft. of gas from the Boulder Sand and 1,500,000 to 5,000,000 cu. ft. from the Hundred Foot Sand. Red Bank Township: 2,000,000 cu. ft. of gas from the Hundred Foot Sand. Wayne Township: 3,000,000 cu. ft. of gas from the Hundred Foot Sand and 4,000,000 cu. ft. of gas was encountered.

Butler County.—Buffalo Township: A small oil field was developed in the Fifth Sand, with the largest well flowing 2,000 bbl. per day.

Fayette County.—Nicholson Township: 1,000,000 to 5,000,000 cu. ft. of gas from the Big Injun Sand. This is the most easterly profitable, productive area in southwestern Pennsylvania.

Greene County.—Center Township: 1,500,000 cu. ft. of gas from the Fifth Sand and 2,000,000 to 5,250,000 cu. ft. in the Fifty Foot Sand. Morgan Township: An extension to an old Fifth Sand gas field was developed, with wells ranging from 1,500,000 to 2,500,000 cu. ft. Washington Township: 2,000,000 cu. ft. of gas in the Fifty Foot Sand.

Indiana County.—West Mahoning Township: 2,000,000 cu. ft. of gas in the Fourth Sand, an extension to an old field.

Jefferson County.—Pine Creek Township: 3,000,000 cu. ft. of gas in the Speechley Sand.

Washington County.—Amwell Township: An unusual well was drilled in with an open flow of 3,000,000 cu. ft. of gas from the Gantz Sand, at a depth of 2582 to 2593 ft. Centerville Borough: 2,000,000 to 3,500,000 cu. ft. of gas from the Big Injun Sand, an extension of an old field. Deemston Borough: 4,000,000 cu. ft. of gas from the Fifth Sand. East Finley Township: 3,500,000 cu. ft. of gas in the Big Injun Sand, 1,000,000 to 2,250,000 cu. ft. of gas from the Fifty Foot Sand; 3,250,000 cu. ft. of gas in the Gordon Stray Sand; and a 30-bbl. oil well. This was the best producer of the year. Fallowfield Township: 3,500,000 cu. ft. of gas in the Fifty Foot Sand, and 4,500,000 cu. ft. of gas in the Big Injun Sand.

West Virginia

In West Virginia, the most unusual development was the striking of gas in Monroe County. The Boozo Gas Co. Inc., drilled in its No. 1

well at a depth of 3000 ft., and obtained a gas well with an open flow of 250,000 cu. ft. The second well drilled close by, on the Shumate farm produced 1,000,000 cu. ft. from the same horizon. The third well, only about ¼ mile from the second well, was drilled to a depth of 4000 ft., with no production. The fourth well is being drilled at present. A great number of leases have been taken in Red Sulphur, Wold Creek and Springfield districts, on the strength of these two wells. This is of interest because it established a new eastern limit for commercial gas production in West Virginia.

Following is a list of other unusual developments in West Virginia during 1930:

Boone County.—Sherman District: 1,500,000 cu. ft. of gas from the Berea Sand, at a depth of 2545 feet.

Cabel County.—Grant District: 1,000,000 cu. ft. of gas.

Calhoun County.—Center District: 2,000,000 cu. ft. of gas in the Salt Sand at a depth of 1510 ft. and 1,000,000 cu. ft. in the Big Injun Sand at a depth of 2046 ft. Sheridan District: 2,900,000 cu. ft. of gas in the Big Injun Sand. This well is 2 miles west of Brookville. Also, 1,000,000 cu. ft. of gas in the Keener Sand. Sherman District: A 50-bbl. oil well in the Big Injun, at a depth of 2110 feet.

Clay County.—Henry District: A 120-bbl. oil well from the Big Lime.

Doddridge County.—Central District: 1,500,000 cu. ft. of gas from the Berea Sand. Cover District: 6,500,000 cu. ft. of gas from the Big Injun, near the Gilmer County line and 3 miles east of Auburn. Also, 8,500,000 cu. ft. of gas from the Big Injun. Another well nearby made 6,500,000 cu. ft. of gas from the Big Injun. There is no additional drilling at the present time.

Gilmer County.—Troy District: 8,500,000 cu. ft. of gas from the Big Injun Sand at 1905 ft. and 8,000,000 cu. ft. from the Big Injun at 1907 ft. De Kalb District: 1,000,000 cu. ft. of gas from the Big Injun Sand at a depth of 2137 feet.

Kanawha County.—Big Sandy District: 1,250,000 cu. ft. of gas from the Big Injun Sand. Cabin Creek District: 3,000,000 cu. ft. of gas from the Berea Sand at a depth of 2293 ft., and 2,500,000 cu. ft. from the Big Lime at a depth of 1400 ft. Malden District: 1,200,000 cu. ft. of gas. Washington District: 2,000,000 cu. ft. of gas.

Lewis County.—6,000,000 cu. ft. of gas.

Lincoln County.—Sheridan District: Two miles west of Hamlin a well gave 4,000,000 cu. ft. of gas from the Big Lime. The majority of the production from this field has been obtained from the Berea Sand.

Marshall County.—Cameron District: 3,500,000 cu. ft. of gas from the Big Injun Sand at 1772 to 1867 ft. The rock pressure is 450 lb. Also, 2,000,000 cu. ft. of gas from the Gordan Sand. Liberty District: 2,500,000 cu. ft. of gas from the Big Injun Sand, 7 miles west of Littleton.

Mingo County.—Harvey District: 8,000,000 cu. ft. of gas at a depth of 975 ft., and 1,500,000 cu. ft. from the Maxton Sand.

Monongalia County.—Cass District: 3,000,000 cu. ft. of gas from the Bayard Sand.

Ritchie County.—Murphy District: 3,300,000 cu. ft. of gas from the Maxton Sand, ½ mile north of Mahone. Also, 3,000,000 cu. ft. from the Gas Sand, 1,000,000 cu. ft. from the Big Injun Sand and a 30-bbl. oil well from the Salt Sand. Sonan District: 1,000,000 cu. ft. of gas from the Big Injun Sand at 2203 feet.

Roane County.—Curtiss District: The outstanding feature in this district is the drilling of a deep well by the United Fuel Gas Co., which is expected to reach a depth of 8000 ft. At the present time, they are drilling around 5500 ft. Reedy District:

A 150 to 200-bbl. oil well from the Berea Sand. Sheridan District: 1,000,000 cu. ft. of gas. Smithfield District: 1,000,000 cu. ft. of gas.

Wayne County.—Butler District: 3,000,000 cu. ft. of gas from the Corniferous Lime at a depth of 3347 ft., and 3,000,000 cu. ft. from the Niagara Lime at a depth of 3721 feet.

Wetzel County.—Church District: 2,000,000 cu. ft. of gas in the Big Injun Sand, and 1,500,000 cu. ft. in the Fourth Sand. Proctor District: A well was recently completed on the S. A. Arrick farm, and was good for 1,500,000 cu. ft. in the Maxton and Gordon sands. This well is especially interesting as it is the first well known to the writer which was located by the geophysical method.

Wirt County.—Burning Springs District: 1,500,000 cu. ft. of gas from the Maxton Sand.

Ohio

Following is a list of the unusual developments in Ohio during 1930:

Allen County.—Bath Township: A 40-bbl. oil well from the Trenton Sand at a depth of 1372 ft., and a 25-bbl. oil well from the Trenton Sand at a depth of 1330 to 1395 ft. These wells are near the old Lima field.

Athens County.—York Township: 4,500,000 cu. ft. of gas from the Clinton Sand. This is a new field opening up near the town of Nelsonville. Also, 1,000,000 to 1,500,000 cu. ft. from the Berea Sand at a depth of 980 ft., and 1,200,000 cu. ft. of gas per day from the Clinton Sand at a depth of 3202 feet.

Belmont County.—Southeast Township: A 700-bbl. oil well in the Keener Sand.

Coshocton County.—Pike Township: 3,000,000 cu. ft. of gas from the Clinton Sand, and a 50-bbl. oil well from the Clinton Sand. Perry Township: A 190-bbl. oil well in the Clinton Sand at 3131 to 3177 feet.

Fairfield County.—Pleasant Township near Lancaster: 5,000,000 cu. ft. of gas from the Clinton Sand at 3254 feet.

Guernsey County.—Wheeling Township: Fifty to 110-bbl. oil wells in Niagara Lime, at depths ranging from 3500 to 3680 ft., also 750,000-cu. ft. gas wells in the Oriskany Sand.

Hardin County.—Pleasant Township: A 300-bbl. oil well.

Hocking County.—Benton Township: 2,000,000 cu. ft. of gas at 2399 feet.

Holmes County.—Richland Township: Clinton Sand gas field, wells from 2,500,000 to 5,000,000 cu. ft. of gas. Hardy Township: Eighty-five to 165-bbl. oil wells in Clinton Sand, and 1,000,000 cu. ft. of gas from the Clinton Sand. Washington Township: 1,500,000 cu. ft. of gas from the Clinton Sand at a depth of 3,000 feet.

Huntingdon County.—Near Huntingdon: 1,000,000 cu. ft. of gas from Clinton Sand.

Jay County.—Penn Township: A 50-bbl. oil well in the Trenton Sand.

Knox County.—A 100-bbl. oil well in Berea Sand, and 1,000,000 to 2,000,000 cu. ft. of gas in Clinton Sand.

Lawrence County.—Dennison Township: A 140-bbl. oil well in "Wrigley" Sand at 1267 to 1276 feet.

Licking County.—Hanover Township: A 40 to 110-bbl. oil well in Clinton Sand, at a depth from 2800 to 2900 ft., also 2,500,000-cu. ft. gas wells from Clinton Sand. Small oil and gas wells also were found in Berea Sand. Fallsbury Township: A 100 to 225-bbl. oil well in Clinton Sand at 2860 to 3050 feet.

Lorain County.—This is Clinton Sand development, with average of 2,000,000-cu. ft. gas wells.

Medina County.—This is also Clinton Sand development; 2,000,000 to 4,000,000-cu. ft. gas wells.

Monroe County.—Benton Township: A 1,000,000-cu. ft. gas well from Corniferous Lime, at 691 ft. Salt Creek Township: A 1,000,000-cu. ft. gas well from Corniferous Lime, at a depth of 750 ft. The rock pressure is 230 pounds.

Muskingum County.—Clay Township: A 150 to 300-bbl. oil well in Clinton Sand, at a depth of 3460 to 3520 ft. Perry Township: 3,000,000-cu. ft. gas wells in Clinton Sand. Jackson Township: A 300-bbl. oil well in Clinton Sand, at a depth of 3095 to 3135 ft. Reading Township: A 1,000,000-cu. ft. gas well in Clinton Sand, at a depth of 2990 ft. Hopewell Township: A 500-bbl. oil well in Clinton Sand, at a depth of 3192 to 3249 ft. Wayne Township: A 2,000,000-cu. ft. gas well in Clinton Sand. Brush Creek Township: 2,000,000 to 4,000,000-cu. ft. gas wells in Clinton Sand at a depth of 4100 feet.

Perry County.—Harrison Township: 2,000,000 to 3,500,000-cu. ft. gas wells from Clinton Sand, also 50 to 200-bbl. oil wells from Clinton Sand. Reading Township: 1,000,000 to 2,000,000-cu. ft. gas wells in Clinton Sand at 3000 to 3150 feet.

Richland County.—1,000,000 to 2,000,000-cu. ft. gas wells in Clinton Sand.

Sandusky County.—Ballville Township: A 1,000,000-cu. ft. gas well in Trenton Sand, at 1375 to 1480 feet.

Stark County.—This is Clinton Sand production; 2,000,000 to 4,000,000-cu. ft. gas wells. Jackson Township: 8,000,000-cu. ft. gas well in Clinton Sand. This means new possibilities.

Summit County.—Newburg production, average 1,500,000 cu. ft., also 1,000,000 to 8,000,000-cu. ft. wells from Clinton Sand.

Tuscarawas County.—A 6,500,000-cu. ft. gas well in Niagara Lime, 100 to 150-bbl. oil wells in Niagara Lime, and 1,000,000 cu. ft. of gas in the Oriskany Sand. Washington Township: 2,000,000 cu. ft. of gas in the Niagara Lime at a depth of 3625 ft., a 100-bbl. oil well in Niagara Lime at a depth of 3694 ft., and a 180-bbl. oil well at a depth of 6641 ft. Oxford Township: A 2,000,000-cu. ft. gas well from Niagara Lime.

Vinton County.—Knox Township: A 2,000,000-cu. ft. gas well in Clinton Sand.

Washington County.—Independence Township: A 75-bbl. oil well.

Wayne County.—1,000,000 to 3,000,000-cu. ft. gas wells in Clinton Sand.

Wyandot County.—Tynnchtee (Old Lima field): 2,000,000 cu. ft. of gas from 1365 to 1376 ft. in Trenton Lime.

Vigo County.—Prairie Creek Township: A 65-bbl. oil well at a depth of 2222 feet.

Kentucky

The following is a summary of the outstanding developments in Kentucky during 1930.

Allen County.—A 200-bbl. oil well at a depth of 456 ft. This is an extension of the old Scottville field.

Bell County.—A 2,000,000-cu. ft. gas well.

Christian County.—A 2,000,000-cu. ft. gas well at a depth of 569 feet.

Daviess County.—Jones pool: Twenty to 50-bbl. oil wells, also 1,000,000 cu. ft. of gas from Barlow Sand.

Hancock County.—Pellsville pool: A 60-bbl. oil well, and 2,000,000 cu. ft. of gas from Barlow Sand.

Hart County.—Horse Cave field: 10,000,000-cu. ft. gas well at a depth of 316 ft. in the Black Lime, and 100 to 300-bbl. oil wells. There are approximately 50 new wells drilling. At mid-December a well came in, producing 2500-bbl. per day from Corniferous Lime. It is the largest well ever drilled in western Kentucky.

Henderson County.—60 to 100-bbl. oil wells in Niagara Lime, 650 to 800 ft. deep.

Hopkins County.—A 3,500,000-cu. ft. gas well.

Johnson County.—A 3,000,000-cu. ft. gas well in Maxton Sand, 1000 ft. deep.

Metcalf County.—A 4,500,000-cu. ft. gas well.

McLean County.—A 50-bbl. oil well in Stray Sand, at a depth of 1123 ft. Turkey Creek District, near Ashland: A 2,000,000-cu. ft. gas well.

Muhlenberg, 10 miles southwest of Greenville: A 6,000,000 to 10,000,000-cu. ft. gas well at a depth of 863 ft., and a 45-bbl. oil well 12 miles southwest of Greenville, at a depth of 1150 feet.

Ohio County.—150 to 250-bbl. wells between the Burford and the Barnett Church pool, at a depth of approximately 650 ft. Also, a 2,750,000-cu. ft. gas well at a depth of 330 ft., 3 miles southeast of Whitesville, a 100-bbl. oil well at 380 ft. and 1,000,000 cu. ft. of gas at a depth of 728 feet.

Perry County.—A 5,000,000-cu. ft. gas well.

Pike County, near Alfred: A 4,000,000-cu. ft. gas well, at a depth of 1600 feet.

Roane County, Curtis Township: A 1,500,000-cu. ft. gas well in Salt Sand at a depth of 1761 feet.

Webster County.—4,000,000 cu. ft. of gas at a depth of 500 feet.

Tennessee

Northern Tennessee is being developed more extensively now than at any time during the past several years, and in the Sunbright field, wells are obtained with an open flow of 1,000,000 cu. ft. or more.

Petroleum Production in Middle Western States, 1930

By R. B. Newcombe,* Lansing, Mich.

(New York Meeting, February, 1931)

Despite abnormal economic conditions and the unhealthy state of the petroleum industry, 1930 closed without any marked decline in total production of oil in the Middle Western States. The most accurate figures available would indicate for this district an output of close to 25,000,000 bbl. for 1930 as compared to 26,000,000 bbl. for 1929. This can be accounted for by the settled nature of a great many of the wells producing in this area and the favorable geographical position, which affords adequate refining and marketing facilities.

The only new flush production field discovered in the area was the Legrande oil pool in southeastern Hart County in western Kentucky, where wells up to 1000 bbl. initial have been reported from a shallow depth. Important extensions have been found in a number of central Ohio fields, and activity in the central Michigan area resulted in new pools along the northwest trend of the Mt. Pleasant structure. These new districts, known as the Leaton and Vernon pools, have not yet reached the scope of the Mt. Pleasant field proper, and although the structure is similar, sand conditions are not strictly analogous.

Wildcatting was retarded somewhat by the scarcity of market for oil and many important wells were shut down for several months. This has not shown such a profound effect on production as the reticence of operators to drill inside proven locations. The major companies have not been able to dispose of their oil and the smaller operating units are having trouble financing their projects. The result is that oil in sight is not being produced and output is suffering accordingly.

Another important effect on production was the introduction of proration by the major crude purchasers and a voluntary shut-down by Kentucky operators. This step became necessary because of the glutting of lake port refineries with Mid-Continent oil, and was not fostered by regulating state bodies, as in the case of the southwestern states. Small refining units have sprung up to meet this situation in a number of instances but they have experienced some difficulty in disposing of their product because of "dumping" tactics from other quarters.

New refinery outlets on the Great Lakes and new pipe line connections should tend to alleviate this difficulty during the coming year. The

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expansion of the old Paragon refinery at Toledo through acquisition by the Gulf companies, the completion of the Empire Oil & Refining Co. refinery at East Chicago, Ill., and the new Pure Oil Co. refinery nearing completion at Toledo should have their effects on the market outlet for the states of Illinois, Indiana, Kentucky, Ohio and Michigan.

Natural gas developments mark the present trend in the petroleum industry and this influence is being felt in the Middle Western States as much as anywhere in the country. Pipe lines projected from Kentucky to Detroit and from the Texas Panhandle and Western Kansas to Chicago and Indianapolis may possibly serve as significant outlets for local natural gas output in the future. Already leasing and gas sale and purchase contracts are being effected by large gas-distributing concerns in the states of Kentucky and Michigan. The immense gas reserves in eastern Kentucky and the so-called "Marshall" gas in central Michigan are attracting considerable attention and probably will be extensively developed when pipe lines afford opportunity for outlet. These areas will be greatly favored by the transportation differential over long-distance transmission and smaller wells can therefore be produced profitably.

The natural gas production for the Middle Western States during 1929 was as follows, in millions of cubic feet: Illinois, 2,983; Indiana, 1,012; Kentucky, 24,588; Michigan, 4,526; Ohio, 57,936. No report which includes all the states of this review is available for the 1930 period.

During 1930 Kentucky led the group of Middle Western States in total oil production. The Kentucky output came largely from the Tri-County and Legrande fields and in 1929 the former section yielded more than one-half the oil produced in the state. Production totals indicate a steady increase in output for the five Middle Western states since 1926 and up to 1930. This is due to new production in western Kentucky, the growth of Michigan as an oil-producing state, and a small increase on the part of Indiana.

Total production of oil from the Middle Western States for 1930 was as follows:[1] Illinois, 5,766,000 bbl.; Indiana, 1,000,000; Kentucky, 7,513,000; Michigan,[2] 3,966,646; Ohio, 6,636,000; total, 24,881,646 bbl. Figures on monthly production of crude oil have been compiled by the U. S. Bureau of Mines.

Production and Development by States

The various states will be discussed separately with particular attention to completion data and the counties that were centers of activity during 1930. Much of this material has been furnished by those who are

[1] *Oil & Gas Jnl.* and U. S. Bureau of Mines estimates for November and December.

[2] Michigan State Tax Commission figures.

more familiar with each individual state and thoroughly understand the scope of development.

Illinois

The Dupo field in Sugar Loaf township, St. Clair County, and adjoining territory continued to be the scene of greatest activity in Illinois. This field, which is in the southwestern part of the state south of East St. Louis, produces its oil from the Kimmswick (Trenton) limestone at depths ranging from 500 to 800 ft. The discovery well was brought in by the Ohio Oil Co. at 660 ft. and a tremendous town-lot drilling campaign resulted. At the close of 1929, there were 225 producing wells, of 252 that had been drilled.

According to Bell,[3] "widespread adverse economic conditions in the oil industry are reflected in Illinois by an 8.5 per cent. decrease in the annual production from that of 1929 and by a marked decrease in the number of wells drilled. Approximately three-fourths of the decrease in production is the result of the 25 per cent. curtailment, effective September 1, according to the agreement of the southeastern Illinois operators. No important new pools or new producing formations were discovered in 1930. Few of the wildcat wells drilled were favorably located with respect to geologic structure. Unless there is a substantial increase in crude-oil prices it is unlikely that there will be any marked revival in drilling activity during 1931. If there is no change in the present proration agreement it is estimated that Illinois will produce 5¼ million barrels of oil in 1931." Of the 253 wells drilled during the year, 120 produced oil, 14 gas and 119 were dry holes.

Indiana

During 1929 there was very little new production in Indiana, although some intensive leasing occurred in the Kankakee Valley. At the beginning of 1930 drilling increased in the west and southwest part of the state and better oil producers were found in the Oakland City field of Pike County. At the close of the year more wells had been completed in Indiana than during the preceding year. Simpson[4] says that, "there was definite activity in 42 of the 92 counties in the state, and commercial quantities of oil or gas were found in 20 of these. Leases were taken or geological work carried on in many of the other counties. The total initial production of new wells did not change materially, nor did the percentage of dry holes completed.

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[3] A. H. Bell, Petroleum Geologist, Illinois State Geological Survey. Personal communication, by permission of the Chief, Illinois State Geological Survey.

[4] P. F. Simpson: Assistant State Geologist and State Gas Supervisor, Indianapolis, Indiana. Personal communication.

"Drilling costs have changed little, though the prices of crude oil have dropped. The latter, together with the depression in financial circles, has caused a decrease in drilling during the last half of 1930. Production dropped off sharply during the last quarter of the year, owing to proration.

"Very little drilling has been done in the old Trenton oil field, which includes parts of Adams, Blackford, Delaware, Grant, Jay, Madison, Randolph and Wells counties. The wells that were brought in were small, and are located in areas once thought not worth testing. It is likely that small pools are yet to be found at varying distances from the edge of the main field, since the general structural conditions are favorable. The local conditions cannot easily be ascertained, because of the thick mantle of glacial drift which is generally present. Electrical prospecting may be effective in locating these small domes. In nearly all of the northern and eastern portions of the state, the Trenton limestone is the only formation in which oil and gas may be expected.

"A small oil well was completed near the state road, 5 miles north of Westfield, in Hamilton County, where a small dome had been indicated by old gas-well logs. Further testing is necessary before profitable production can be forecast.

"A small gas well south of Huntington caused the drilling of two dry holes on the same farm. Several other wildcat wells were dry, including the deep test in northwestern Lake County near Chicago.

"The gas wells completed in the southeastern counties were all in known gas territory, and were drilled by local gas companies to sustain their present production. The tests outside of this area were failures.

"*Southwestern Oil Fields.*—The present production in the southwestern counties is largely from Upper Mississippian and Lower Pennsylvanian horizons. No new fields of consequence have been discovered and the new wells have barely been large enough to sustain the state's total oil production at about 1,000,000 bbl. for 1930.

"*Vigo County.*—This county again led in average initial production, since nearly all of the new wells were in the Siosi field, where the Corniferous limestone is the producing horizon. The deep test drilled in the center of the pool was dry in the Trenton, but found a new productive horizon below the known oil-bearing horizons. Many of the wells have been drilled to this stratum, but some have encountered water. The initial production of the deep well was 200 bbl. per day.

"*Sullivan County.*—A wildcat well on a promising dome in Turman township was completed a 10-bbl. well, and a dry hole was completed near it. No other important tests were drilled.

"*Knox County.*—Three tests drilled in the southern section were failures but a good gas well was found in Busseron township. The production was 3,000,000 cu. ft. at 322 lb. pressure, from a sand at 705 to

714 ft. Three other gas showings were reported at shallower depths. This discovery should arouse some interest in Knox County, since no commercial quantities of gas had been found there, although it had been found on all four sides.

"*Daviess County.*—The finding of a 1,000,000-cu. ft. gas well south of Washington indicates that a small pool may be developed there. This was the largest well yet found in the county.

"*Pike County.*—Nearly one-third of the completions in the state were in this county, where two fields were being developed. The Union oil pool in the northwest corner of the county furnished the best wells, the largest starting at 225 bbl. per day. There is still good territory to be developed on the structure, which has been partly outlined. Many of the gas wells were in the Alford pool, east of Petersburg, in which development has been practically completed. It was discovered in 1929. A new gas well just north of Petersburg may indicate a pool there; other wells are being drilled near it. One or two other gas wells may be considered discovery wells, after wells being drilled near them are completed.

"*Gibson County.*—Drilling activity fell far below normal in this county and the only discovery of importance was in a deep test which is not yet completed. It passed through a 1,000,000-cu. ft. gas flow at about 3500 ft., probably in Devonian strata. No other well has tested the Devonian within about 40 miles of this location, which is in Columbia township.

"*Spencer County.*—No new pools have been discovered, though the Troy pool, in the southeastern corner of the county, has been extended in two directions by small wells.

"*Warrick County.*—Two of the dry holes were on promising structures. There is no production in the county at present.

"*Vanderburgh County.*—A well completed late in December north of Evansville produced 7 bbl. initial at 920 ft. and gives promise of active development in this area.

"*Perry County.*—In spite of numerous earlier failures, testing was active, and one small pool was found near Gerald. No well defined structure was evident, but the wells produced 8 to 12 bbl. initial, with some gas, from a depth of about 120 ft. Several small gas wells were also completed near Bristow, on a small dome discovered last year.

"*Monroe County.*—Of the dozen or so wells drilled along the eastern edge of Monroe County, only a few were successful in finding gas, and none found oil. The gas comes from the Corniferous limestone at about 675 ft.; the Trenton was tested but was found dry.

"*Summary.*—Oil production has no more than held its own in Indiana during 1930, and the prospects for 1931 are for a decrease, unless prices strengthen. There is some drilling yet to be done in known pools, but not enough to cause a decided increase in the total production for the state.

"Gas tests may be expected to increase the output, since prospects for several new pools seem bright. The building of several proposed gas pipe lines should also increase activity.

"During 1930 there were 216 wells drilled, of which 74 were oil wells, 45 gas wells and 97 dry holes."

Michigan

The output of Michigan declined in 1930 to 3,966,646 bbl. because of the loss of flush production from the Muskegon field, the smaller size of wells in the Mt. Pleasant field, the suspension of drilling activity on proven locations and the proration schedule of crude-oil purchasers. Although Mt. Pleasant was leading Muskegon at the close of 1929, the Muskegon field produced over twice as much oil as the Mt. Pleasant area for the entire year. Many Muskegon gas wells went on to oil and at the close of the year more than 80 per cent. were producing from the Dundee. During 1929, some inside locations were drilled in the old Saginaw pool and extensions were found at Mt. Pleasant, which developed into the Leaton pool north and east of the city. Discovery of gas in southern Clare County about 20 miles north of Mt. Pleasant resulted in considerable drilling in that district. The productive horizon of Upper Mississippian age is referred to as the "Marshall" gas sand, but in reality it is a stray sand which is rather persistent in the lower part of the Michigan series in the central part of the state.

During 1930 there was more wildcatting in Michigan than in all other fields of the Middle West, and completions were made in 36 counties. The principal development was in the central part of the state, where two new important productive districts were discovered—the Vernon pool in Northern Isabella County between Mt. Pleasant and Clare and the Broomfield gas area west of Mt. Pleasant. Other important showings were also found in central Michigan and this region promises to be a center of interest for some time to come. The significant feature of this area is the quantity of shallow gas in the Michigan Series "Stray" sand which is furnishing wells up to 10,000,000 cu. ft. from depths of 1300 to 1400 ft. The resources of this horizon have scarcely been touched and only await pipe line facilities to bring about adequate development. Contracts and options have been allowed for taking the gas but no active operations for laying a line have been commenced. The present potential open flow of gas from the Michigan Series aggregates about 40,000,000 cu. ft. and the producing area is spreading out considerably.

Other new production was found in the southern part of the state from the Trenton in western Monroe County, from the Traverse at a shallow depth in southeastern Cass County and from the Traverse in central Shiawassee County. Localities of important showings in Michigan were in the western part; southern Allegan County, southern Oceana County

and southwestern Mason County; central part, southern Osceola County, eastern Mecosta County, northern Gratiot County, and northeastern Bay County; southeastern part, central Livingston County, northeastern St. Clair County and southeastern Washtenaw County.

The principal producing horizon in Michigan is the Dundee limestone of Middle Devonian age, which varies in depth from 1000 to 3800 ft., depending on locality. Other important "sands" are the Michigan Series Stray, the Berea, the Traverse and Monroe. Deep drilling on the Saginaw, Mt. Pleasant and Muskegon structures has shown some quantities of oil and gas but results are not particularly promising.

Marketing facilities are afforded by independent gathering systems in the fields, the Pure Oil 38.7 mile 6-in. line from Mt. Pleasant to Bay City and the Dixie pipe line to lake level at Muskegon. The principal transportation is by rail and boat to lake port refineries at Chicago, Sarnia, Ont., Toledo and Cleveland. Local refineries at Mt. Pleasant and Muskegon take a portion of the output. Prices for Michigan crude have fluctuated greatly throughout 1930 on account of the general economic condition of the industry and the limitations of local markets, and the year marked the withdrawal of the Sun Oil Co. from the Saginaw field as a purchaser of crude oil.

Drilling activity, consisting of 303 completed wells, resulted in 155 oil wells, 25 gas wells and 123 dry holes.

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Oil and Gas Development in South Arkansas, North Louisiana and Mississippi, 1928 to 1930

By H. K. Shearer,* Shreveport, La.

(New York Meeting, February, 1931)

The principal events in the oil history of south Arkansas, north Louisiana and Mississippi in 1930 have been: In Arkansas, very little activity, except for discovery of deep oil production at Urbana, and completion of the first oil well in Miller County. In Louisiana, continued development of the Zwolle area, bringing production up to about 10,000 bbl. per day; practically complete development of the Carterville oil-producing area; discovery and drilling of the rather disappointing Holly area, and discovery of Trinity gas production at Sugar Creek, Claiborne Parish and Rodessa, Caddo Parish. In Mississippi, discovery of the Jackson gas field, in Hinds and Rankin counties.

Proration of oil runs was not put in effect in these areas during 1930, because the natural decline of the older fields brought production below the demands of local markets. The only effect of the oversupply and low price of oil was the curtailment of some drilling which might otherwise have been done. Drilling in Arkansas reached the lowest stage since the discovery of oil, with less than 100 completions. Louisiana showed some increase in drilling over 1928 and 1929, but almost half of the wells were drilled primarily for gas rather than oil.

As no review on north Louisiana production has been prepared since 1927, and there was none on south Arkansas for 1928, the developments of the three years, 1928, 1929 and 1930 are here briefly discussed.

Table 1.—*South Arkansas* Well Completions*, 1928 *to* 1930

	1928				1929				1930			
	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total
Less than 3000 ft.	57	15	20	92	71	11	28	110	36	1	26	63
More than 3000 ft.	104	6	110	220	18	2	65	85	12	0	16	28
Totals	161	21	130	312	89	13	93	195	48	1	42	91

* Includes 25 counties: Arkansas, Ashley, Bradley, Calhoun, Chicot, Clark, Cleveland, Columbia, Dallas, Desha, Drew, Grant, Hempstead, Hot Spring, Howard, Jefferson, Lafayette, Lincoln, Little River, Miller, Nevada, Ouachita, Pike, Sevier and Union.

* Geologist, Standard Oil Co. of Louisiana.

Tables 1 and 2 show the number of wells completed during the last three years in 25 counties of south Arkansas and 29 parishes of north Louisiana.

Table 2.—*North Louisiana* Well Completions*, 1928 *to* 1930

	1928				1929				1930			
	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total
Less than 3000 ft.....	38	181	117	336	131	259	111	501	147	232	174	553
More than 3000 ft.....	24	50	76	150	13	19	41	73	75	14	85	174
Totals............	62	231	193	486	144	278	152	574	222	246	259	727

* Includes 29 parishes: Avoyelles, Bienville, Bossier, Caddo, Caldwell, Catahoula, Claiborne, Concordia, De Soto, East Carroll, Franklin, Grant, Jackson, La Salle, Lincoln, Madison, Morehouse, Natchitoches, Ouachita, Rapides, Red River, Richland, Sabine, Tensas, Union, Vernon, Webster, West Carroll and Winn.

South Arkansas

Champagnolle.—The Champagnolle oil field was discovered in 1927, but only four producing wells were completed during that year. Intensive drilling during 1928 accounted for 112 oil wells, but 17 gas wells and 75 dry holes showed the spotted character of production. Drilling fell off in 1929 and 1930. However, several good wells have been completed during the latter months of 1930 in sec. 12, 17 S., 14 W. This field is not entirely defined by drilling to the east and northeast, so some extension is still possible.

Production comes from three sands, at approximately 2750, 3000 and 3200 ft. The two lower sands, which are most important, are in the Trinity red beds. Champagnolle is the first field to obtain any important production from this Lower Cretaceous red beds formation, and has given encouragement for other deep prospecting in formations not previously considered very favorable for either origin or accumulation of oil or gas.

Smackover.—Eighty-three producing wells were drilled in the Smackover area during the past three years. Most of these were small wells drilled to the Nacatoch sand when small extensions to the north and northeast were discovered in 1928 and 1929. Production of the field as a whole and of each separate sand shows normal decline. The relative importance of the Smackover field is declining, and its production in 1930 was about 78 per cent. of the Arkansas total, but only 45 per cent. of the combined Arkansas-north Louisiana yield.

Urbana.—The discovery well in the Urbana 3500-ft. sand was the Marine Oil Co., Thompson A-3, sec. 10, 18 S., 13 W., Union County, completed Jan. 19, 1930, flowing 425 bbl., depth 3535 ft. Some gas had

been produced from shallower sands in the same area in 1927, but this was already exhausted. By the end of 1930, seven producing wells had been completed, all near the center of sec. 10, 18 S., 13 W., with three deep dry holes within a 1-mile radius. A well ¼ mile west of production was a failure at 4501 feet.

The producing sand is deeper than the Champagnolle pay, being about 600 ft. below the top of the red beds. The total production for 1930 was about 230,000 bbl., and the average daily production at the end of the year about 1000 barrels.

Other Fields.—The other fields of Arkansas—Bradley, El Dorado, East El Dorado, Lisbon, Mt. Holly, Irma and Stephens—showed normal production declines, with no notable extensions and very little drilling activity.

The Mt. Holly or McDonald area, sec. 25, 15 S., 18 W., discovered in July, 1929, had six producing wells in an area little larger than 40 acres at the end of that year. Drilling in 1930 brought only two more dry holes, and the production is only 70 bbl. per day.

Wildcat Areas.—Wells producing some oil were drilled in two wildcat areas, but the discoveries have not yet developed into real oil fields.

The Modisette Drilling Co., Union Saw Mill No. 2., sec. 14, 18 S., 14 W., Union County, was completed on Feb. 1, 1930, pumping 50 bbl., depth 2238 ft. Three other small wells were later completed in the same section. The oil accumulation is in the Nacatoch sand on a minor fold between the East El Dorado and Urbana structures.

Vincent Lenz et al. completed the Johnson No. 1 well, sec. 24, 15 S., 26 W., flowing 50 bbl. of 29.5° gravity oil, on July 30, 1930, this being the first oil well in Miller County. The same party had previously drilled six dry holes in this township, besides five drilled by others, but some of the older wells had cored enough oil sand to encourage drilling. The oil sand is in the lower Cretaceous Trinity beds, about 300 ft. below the top of the red beds. This well increases the general prospects of Lower Cretaceous production in southwestern Arkansas, although it does not prove up any important producing area. An offset well to the north did not prove productive down to 3600 ft., and a well a little over a mile southeast was abandoned below 3100 feet.

The rise and fall of magnetometer exploration occurred in 1928 and 1929. Early in 1928 magnetic surveys were made over large areas, and very pronounced magnetic highs were found in certain parts of southeastern Arkansas, expecially in Ashley, Chicot, Cleveland and Drew counties. In September, 1928, the Texas Co., Gay No. 1, sec. 33, 16 S., 4 W., Ashley County, which was located on one of the magnetic highs, drilled into igneous rock at 3185 ft. Later the Texas Co., Hammond No. 1, sec. 23, 17 S., 2 W., Chicot County; the Arkansas Natural Gas Co., Tate No. 1, sec. 4, 9 S., 11 W., Cleveland County, and the Ohio Oil Co.,

Jerome Hardwood Lumber Co. No. 1, sec. 13, 15 S., 4 W., Drew County were also abandoned in igneous rock, at depths below 3000 ft. In all, 13 wells were drilled on the basis of magnetic disturbances in the four counties mentioned in 1928 and 1929, and one more in 1930, without even a showing of oil or gas. The igneous rock is evidently in the form of plugs, sills or flows intruded into or through the Lower Cretaceous, but without any effect on the Upper Cretaceous structure.

Evidence from drilling done so far shows that magnetic anomalies depend on the character of the basement rocks, but if such anomalies have any relation to structures favorable for oil or gas accumulation, the methods of interpretation are still to be worked out.

North Louisiana

Bellevue.—The first really deep test on the Bellevue structure, the Humble Oil & Refining Co., Bliss & Wetherbee No. 30, sec. 15, 19 N., 11 W., was abandoned in March, 1928, at a depth of 5302 ft., in the lower marine beds of the Trinity group, being stratigraphically the deepest well in Louisiana.

In October, 1929, the H. I. Morgan et al., Wetherbee No. 1, sec. 21, 19 N., 11 W., was completed as a 6,000,000-cu. ft. gas well at 1872 ft. This is the discovery well of a gas area on the southwest flank of the Bellevue structure, producing from the basal Upper Cretaceous sands and the Lower Cretaceous Glen Rose formation. The same party has since completed four more gas wells, six dry holes, and one well which started producing about 500 bbl. of oil per day in August, 1930, but fell off rapidly and stopped flowing in November. On account of the intense folding and faulting of the Lower Cretaceous beds, and a great unconformity at the top, no location can be considered proved in advance of drilling.

Caddo.—Drilling in the Pine Island deep oil-producing area (Glen Rose production) continued during 1928, when 14 oil producers and 12 dry holes were completed. In 1929 there were two oil wells, one gas well and six dry holes. No deep wells were drilled in 1930. During the three years 109 shallow oil producers (less than 3000 ft.) were completed in the old Caddo fields, mostly in the chalk rock, Nacatoch, and "Blossom" sands.

The Dixie oil pool, southeast of the old Caddo producing area, was discovered by the D. C. Richardson, S. S. Hunter estate No. 1, sec. 17, 19 N., 14 W., completed in May, 1929, at a depth of 2422 ft. Thirty-nine producers and 30 dry holes were drilled in 1929, three producers and six dry holes were added in 1930. The oil comes principally from lenticular sands at the base of the Upper Cretaceous Tokio formation, just above the unconformity at the top of the Lower Cretaceous, but a little oil also comes from the Lower Cretaceous. The production in 1929 was 588,415

bbl. of 42° gravity oil. The 1930 production is estimated at a little more than 400,000 bbl., making a total of just about 1,000,000 bbl. This is included with Caddo light oil in production reports.

Carterville—Sarepta.—Development of the "Giles sand" gas production near Carterville, Bossier Parish started in 1927, when 23 producing wells were completed, between 3000 and 3100 ft. In 1928, 25 more gas wells were drilled. Drilling for gas was at a standstill in 1929, and the gas in the Giles sand was becoming depleted.

The Delaware-Louisiana Development Co., Bolinger No. 4, sec. 38 (32), 23 N., 11 W., originally completed as a gas well at 3078 ft. in June, 1928, was deepened to 4005 ft., then plugged back to 3170 ft. to test a sand showing oil. It was completed in September, 1929, flowing 50 bbl. per day, as the discovery well in the deeper sand in the Carterville area. This sand is near the base of the Upper Cretaceous, probably of Tokio age.

Three more producing wells were completed before Jan. 1, 1930. An active drilling campaign was carried out during the early months of 1930, but the productive area was practically drilled up before the end of the year, 67 oil wells and 29 dry holes being completed. Of these completions 13 producers and 5 dry holes were old gas wells deepened. The productive area is limited to about 900 acres, and many of the wells within this area were too small to be profitable. Daily production reached a maximum of 3692 bbl. on June 1, and had fallen off to 1136 bbl. on Jan. 1,1931.

The Sarepta area, whose production is included with Carterville, is a separate pool in and around sec. 1, 22 N., 11 W., Webster Parish, producing from the "Blossom" or 2700-ft. sand. It had produced a few thousand barrels of oil before 1928, but not much drilling was done previous to the Carterville development in 1930. In this year 22 oil wells were completed. Maximum production, on Oct. 30, was about 1000 bbl. per day, and had declined to 664 bbl. on Jan. 1, 1931.

Cotton Valley.—In 1928 development of the deep gas production, at 4400 to 4700 ft., was continued; with 22 gas wells completed that year, 17 in 1929, and only two in 1930. No drilling was in progress during the latter part of 1930.

The Ohio Oil Co., Bodcaw Lumber Co. No. 38, sec. 15, 21 N., 10 W., was completed in March, 1928, flowing 3595 bbl. per day of light oil at 4683 ft. This stimulated drilling, but only three more small oil wells were completed in the immediate vicinity. Later two other gas wells on the southwest flank of the Cotton Valley structure started producing small quantities of oil.

Haynesville.—No producing wells have been drilled in the Haynesville field during the past three years.

Repressuring of the sand by injection of dry gas was started experimentally with two wells in August, 1929, and was really put in effect when 11 more wells were added in March, 1930. The operations proved

successful from the start, and nine more key wells were put in operation in October and November, 1930.

Average daily production increased from 4525 bbl. in April to 5235 bbl. in November, and at the same time the vacuum on producing wells was reduced from 27 or 28 in. to about 8 in., and the gravity of the oil increased from 34.4° to 35.5°.

Holly.—R. O. Roy completed his Jessie Fuller No. 1 well, sec. 6, 13 N., 13 W., De Soto Parish, in September, 1928, making 20,000,000 cu. ft. of gas, depth 2827 ft.; this being the discovery gas well in the Holly area. He had previously drilled two dry holes, and drilled two more in 1929, before bringing in the discovery oil well, the W. H. Farmer No. A-1, sec. 5, 13 N., 13 W., flowing 2102 bbl., depth 2882 ft., in March, 1930.

Including the discovery wells, 7 oil producers and 5 gas wells had been completed by Jan. 1, 1931, and 19 dry holes had been drilled within a radius of five miles. The oil-producing area is evidently small, but is not yet entirely outlined by drilling. A larger area has gas possibilities.

The oil production comes from a lenticular sand and volcanic ash formation only a few feet above the base of the Upper Cretaceous, which is probably of Woodbine age, corresponding to the productive horizon in the old De Soto-Red River fields. The gas and oil are believed to come from different sand lenses.

Daily production has averaged a little over 1000 bbl. of oil per day since discovery, with a total of over 300,000 bbl. to the end of 1930. The gas is being used only as fuel for drilling operations.

Zwolle.—Principal development of the Zwolle district occurred during 1930, although the real discovery dates back to the completion of the R. L. Gay, Trustee, Bowman-Hicks No. 1 well in the Blue Lake sector, sec. 14, 7 N., 14 W., flowing 50 bbl. at 2130 ft. in November, 1928. As developed at present, the district consists of a number of more or less disconnected oil pools in a crescent-shaped area extending from Blue Lake, sec. 14, 7 N., 14 W. to a point three miles north of Many, in sec. 10, 7 N., 11 W. The length between tips of the crescent is 17 miles, and the greatest width of the producing area from north to south is three miles.

Drilling around the Blue Lake discovery well in 1929 yielded only three more small wells and five dry holes. But 11 miles east-northeast of the Blue Lake production, the R. L. Gay, Trustee, Bowman-Hicks No. A-1, sec. 34, 8 N., 12 W., was completed in November, 1929, as the discovery well in the main Zwolle pool, flowing over 3000 bbl. per day of 41.5° gravity oil at a depth of 2413 ft. This well is in an area where occasional drilling had been done since 1911, with some wells making good showings of oil, but such a large producer was entirely unexpected. Shortly after completion, the discovery well and a block of surrounding

leases were sold to the Benedum-Trees interests, and operated under the name of the Loring Oil Co.

Active drilling in 1930 led to the completion of 59 producing wells, of which only two were in the original Blue Lake area, and 74 dry holes. Production was first extended three miles west of the discovery well to the Zwolle townsite, then five miles east to sec. 4, 7 N., 11 W., with other extensions to the northeast and southeast. Considerable areas are left undrilled, and the belt between Zwolle and Blue Lake remains practically untested, on account of divided lease ownerships and small demand for oil.

Daily production reached a maximum for the year of 10,049 bbl. on Dec. 1, but future development will probably bring higher peaks. Total production for 1930 has been about 1,875,000 bbl. The discovery well has produced much more oil than any other in the field, although one well in sec. 11, 7 N., 12 W., completed in October, 1930, may eventually equal its record. The greater part of the total production has come from five or six large wells.

The depths of producing wells vary between 2130 and 2586 ft. in the Blue Lake area, and between 2187 and 2684 ft. in the area around Zwolle.

The highest Cretaceous formation is a bed of gray, sandy marl, not exceeding 40 ft. in thickness, which seems to represent the entire period of Arkadelphia, Nacatoch and Marlbrook deposition. Below the marl is 400 to 600 ft. of chalk, correlated as Annona on the basis of fossils, then a bed of sand which carries salt water wherever it has been penetrated. A few wells have produced oil from the upper marl, but most of the production is from breaks in the chalk. These breaks do not come at any definite horizon, and are evidently faults or fractured zones. There is plenty of evidence of structural disturbance, as both the top and bottom of the Upper Cretaceous chalk and marl section show considerable variations in elevation, but the best wells have not been found at the highest points on structure.

The Zwolle district is an important oil field, and should produce a great deal of oil in the future. Results of drilling are expected to be about the same as during the past year. Less than one-half of the wells drilled have produced any oil, and only one in four or five was large enough to be very profitable. In advance of drilling, locations offsetting large wells cannot be considered any more favorable than others made at random within the general producing area.

Several wells drilled on down into the Lower Cretaceous have shown nothing else promising for production down to a little more than 4000 ft., although the structural conditions are still imperfectly known, and there may be one or more structures favorable for oil or gas accumulation in the lower sands.

Salt Domes.—No drilling has been done on the interior salt domes of north Louisiana in 1929 and 1930. The Ohio Oil Co., Rolan Acct. 1, No. 2, sec. 5, 12 N., 1 W., Winn Parish, was abandoned in March, 1928, in rock salt at 4947 ft., being the first well drilled into the salt on the Sikes dome. The Humble Oil & Refining Co., Anderson No. 1, sec. 29, 18 N., 5 W., Bienville Parish, was abandoned in June, 1928, in Glen Rose limestone at 4263 ft., being the deepest test near the Arcadia salt dome.

Gas Developments

With the completion of gas lines to Baton Rouge and New Orleans, Birmingham and Atlanta, Memphis, and St. Louis, drilling in the Monroe and Richland gas fields of Morehouse, Ouachita, Union and Richland parishes has been very active. The gas well completions numbered 76, 159 and 92 in 1928, 1929 and 1930, respectively, in the Monroe field; and 45, 58 and 103 in the Richland field.

Routine drilling has been done in the other older fields, especially at Elm Grove and Sligo, Bossier Parish, but there have been no new developments of importance.

On Oct. 15, 1930 the Louisiana Department of Conservation completed a gage of the wells in the Monroe and Richland fields, showing an open-flow capacity of 4,361,414,000 cu. ft. per day from 808 wells in the Monroe field and 4,174,060,000 cu. ft. from 200 wells in the Richland field. Permissible withdrawals amount to 1,080,989,285 cu. ft. per day from Monroe and 656,516,143 from Richland; and actual withdrawals have recently been somewhat more than one-third of the total permissible.

During 1929 and 1930 about 40 per cent. of the gas produced in Louisiana was used for manufacture of carbon black, against 80 per cent. in 1924, which was the year of maximum carbon black production.

Floyd.—The Palmer Corpn., O'Brien No. 1, sec. 7, 19 N., 11 E., East Carroll Parish was completed in May, 1928, producing 51,000,000 cu. ft. of gas from a depth of 2356 ft. A structural high in this area was suggested by wells previously drilled, and the structure was checked by geophysical methods before this well was located. Three more gas wells have since been completed, two in East Carroll and one in West Carroll Parish. The proven productive area is only about two square miles, and is limited by dry holes within a mile southwest, northwest and east. The structure is evidently a Cretaceous high similar to the Monroe and Richland uplifts, although on a much smaller scale.

Rodessa.—Another Trinity gas-producing area in Caddo Parish was opened by the R. W. Norton, Hill No. 1 well, sec. 33, 23 N., 16 W., completed in August, 1930, at a depth of 5506 ft., producing 11,242,000 cu. ft. of gas, with 819 gal. of gasoline per million. The gas comes from

a sand in the Glen Rose formation, below the anhydrite series. Two other wells were drilling at around 5000 ft. at the end of 1930. These wells are on the Rodessa fault structure, where several wells had previously produced a little oil from shallower depths.

Sugar Creek.—The Triangle Drilling Co., Kilpatrick No. 1, sec. 7, 19 N., 5 W., Claiborne Parish, was completed in March, 1930, depth 4558 ft., making about 1,000,000 cu. ft. of gas with a little oil and salt water, as the discovery well of Lower Cretaceous gas production on the Sugar Creek structure. A deeper dry hole had been drilled ½ mile south in 1926. Since March, four larger gas wells have been completed to the north, all in sec. 6, 19 N., 5 W., at depths between 4300 and 4400 ft. The total open-flow capacity is over 135,000,000 cu. ft. Arrangements for pipe line connections had been made and a gasoline plant was under construction at the end of the year.

The gas is produced from a bed of oolitic limestone just below the anhydrite series in the Glen Rose formation of the Lower Cretaceous Trinity group.

Wildcat Areas.—Wildcatting has not been very active in north Louisiana since 1927 and most of the wells drilled were in search of extensions to proven fields. The producers included with wildcats represent no important discoveries, except possibly the Rodessa gas well. There were three reported oil wells in the noncommercial Oakland area, Union Parish and two in the Benson and Grand Cane areas in De Soto Parish, where a little oil has previously been found. Gas wells included seven in the small Lake Bistineau field, Bienville Parish; four near Shreveport and in an extension of the Elm Grove field into Caddo Parish, four near Benson, De Soto Parish; one at Rodessa, Caddo Parish; one near Curtis, Bossier Parish; and one very small well in Tensas Parish.

Gas blow-outs from Eocene formations in Catahoula and Franklin parishes in 1927 started some drilling in these parishes, as well as in Concordia and Tensas, in the central part of the Mississippi basin. There were 21 wells completed in these four parishes from 1928 to 1930, with five still drilling; but the only result was one well rated at 20,000 cu. ft. of gas per day at 712 ft., in sec. 18, 10 N., 10 E., Tensas Parish.

Considerable geophysical work with the magnetometer, seismograph and torsion balance has been done in north Louisiana since 1927. As far as is generally known, the only practical result of this work was the defining of the Floyd gas structure in East and West Caroll parishes.

Deep Drilling

No well more than 5000 ft. deep has ever been drilled in south Arkansas. In north Louisiana 12 wells over 5000 ft. have been drilled since 1927, without important results except at Rodessa.

Mississippi

The Jackson anticline in Hinds and Rankin counties, Mississippi, was mapped by Oliver B. Hopkins, of the U. S. Geological Survey, in 1916. Two wells were drilled in 1917, by the Arkansas Natural Gas Co. and Atlas Oil Co., in secs. 14 and 18, 6 N., 1 E., a few miles north and northwest of Jackson, both of which struck lime rock and chalk at 2500 to 2600 ft. Because of the lack of cores or other good samples from these wells, and the slight knowledge of the normal succession of formations, the importance of the structural disturbance indicated was not fully appreciated at that time.

After several deep tests had been drilled within a 40-mile radius around Jackson, showing the normal succession and thickness of the Eocene formations, the Lion Oil Refining Co., in association with several other major companies, drilled the Misterfeldt No. 1 well, sec. 2, 4 N., 1 E., Rankin County, which was completed in June, 1929. This well was known to be on the south flank of the structural high, but it encountered chalk and limestone, at least part of which is of Cretaceous age, from 3064 to 3502 ft., followed by red shale and sand with interbedded gray shale and limestone down to the total depth of 4075 ft. This proved that the Cretaceous beds had been thrust up almost 2000 ft. higher than their normal position, although the surface structure shows dips of only about 200 ft. to the southeast, southwest and northwest, with no definite closure to the northeast.

The next well of importance was the Home Oil & Gas Co., Rainey No. 1, sec. 13, 5 N., 1 E., Rankin County, which was located on or near a magnetic high, and closer to the center of the surface structure. This well found the top of the chalk at 2509 ft., or 546 ft. higher structurally than the Misterfeldt well. It showed some gas, and returns were lost in the porous formation, but the well was junked while trying to set casing, in October, 1929.

The Jackson Oil & Gas Co., Mayes No. 1, sec. 2, 5 N., 1 E., Hinds County, is credited as the discovery gas well. This well blew in making 2,000,000 cu. ft. of gas with much salt water on Feb. 16, 1930, from a depth of 2568 ft. It was not finally completed, however, until October, 1930, when it made about 20,000,000 cu. ft. of gas after plugging back to 2466 ft.

The Gulf Refining Co., Rainey No. A-1, sec. 13, 5 N., 1 E., offsetting the Home Oil Co. well in the same section, was drilled to 3607 ft. This well found the chalk from 2501 to 2848 ft., but below this, from around 2980 ft. to the bottom, was a mass of igneous rock, in place of the red beds series found in the Misterfeldt well. This Gulf well was later plugged back and made a gas producer from the top of the chalk.

Another well, the Louisiana Gas & Fuel Co., Harris No. 1, sec. 35, 6 N., 1 E., also encountered igneous rock below the chalk, and was abandoned at a total depth of 3239 feet.

Several wells have made small quantities of heavy oil along with gas and salt water, but no commercial oil producer has been completed.

In 1930, up to Dec. 13, 30 gas wells and 13 dry holes were completed in Hinds and Rankin counties.

As outlined by drilling at present, the gas production seems limited to minor highs on the top of the chalk in an area about four miles square. Such productive minor highs have been found in sec. 2, 5 N., 1 E.; sec. 12, 5 N., 1 E.; sec. 15, 5 N., 1 E.; sec. 26, 6 N., 1 E.; and sec. 28, 6 N., 1 E. Dry holes have been drilled in intervening areas, where the top of the chalk is only a little lower.

Only a little gas for drilling operations has so far been taken from the field, so it is not yet safe to make any statement as to total capacity and ultimate production.

The Jackson anticline is a Cretaceous uplift, probably due in part to igneous intrusion, and of the same general type as the Monroe and Richland structures in Louisiana. The limestone and chalk formation which carries the gas is very similar to the Monroe gas rock, but the typical Selma chalk formation, as found on the outcrop and in wells to the north and east, is not found on the Jackson uplift. The chalk at Jackson contains few fossils, and there is still some doubt as to whether its age is late Cretaceous or early Midway, or whether it represents a transition from Cretaceous to Midway. Some fossils of Upper Cretaceous types were found in the underlying red beds series in the Misterfeldt wells, so these red beds must represent the Eutaw or Tuscaloosa formation, and are of later age than the Lower Cretaceous red beds of Louisiana.

Outside of Hinds and Rankin counties, nine wildcat wells, all dry, were completed in Mississippi in 1930. These included two near Natchez, Adams County, two near Meridian, Lauderdale County and one near Amory, Monroe County. No new gas production was found during the year in the Amory district.

The deepest well drilled in 1930, and the deepest in the state except one drilled in 1924 in Scott County, was the Amerada Petroleum Corpn., Campbell No. 1, sec. 24, 12 N., 2 W., Yazoo County, dry at 5198 ft., March, 1930. This well proves a deep syncline north of the Jackson anticline, as it struck the top of the Cretaceous at approximately 4950 feet.

Acknowledgments

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Production and Development Situation of Kansas in 1930

By Henry A. Ley,* Tulsa, Okla.

(New York Meeting, February, 1931)

Kansas ranked fourth on the list of oil-producing states during the year 1930. Progressive statistics show that total production for the year will approximate 42,729,085 bbl. When final figures are compiled for Kansas the production may exceed this estimate, and thereby threaten the all-time record of 43,253,470 bbl. in 1918. Throughout the year the cumulative volume of potential drilled-up production has been increased by new discoveries and by extensions to proven areas in the territory west of the Nemaha (granite ridge) Range. Scattered drilling and leasing operations of a constructive nature occurred, but completions declined to the lowest levels in more than 11 years. Average initial production of current completions climbed to a new all-time high of 512 bbl. to the well. Proration measures were applied to the flush pools. The resulting shut-in potential production, as of December 15, is estimated at 110,000 bbl. This estimate is a wild guess. If all wells of the state were permitted to flow wide open for a period of six months production would not exceed 150,000 bbl. a day. The outstanding development of the year was an intensive drilling campaign in southwestern Kansas, which contributed at least 1,000,000 acres of contiguous natural-gas lands to the natural-gas resources of the United States.

Production and Development

Prospecting for oil in Kansas began shortly after the initial prospecting at Titusville. Operations and interest in the potentialities became active about 1870. This development was restricted to the shallow districts of northeastern Kansas. By 1895 operations had extended southward to the Oklahoma state line and sufficient prospecting had taken place to prove the potentialities of the state. Active prospecting was extended westward by the discovery of oil on the Nemaha Range in Butler County about 1916. The discovery of oil in Russell County added an extensive borderland province in 1923. The important discoveries of oil in Sedgwick County revived interests and operations throughout this territory in 1928. The development of widespread natural-gas lands in extreme southwestern Kansas during 1930 carried active exploration to the western boundary of the state.

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Production.—Kansas has produced about 561,911,491 bbl. of oil since 1889. The highest annual output occurred in 1918, when the state produced 43,253,470 bbl. This is a daily average production of 118,502 bbl., only slightly greater than the curtailed withdrawals of 1929 and 1930, and about 17 per cent. greater than the average daily output for the decade 1920 to 1929. The average initial daily production of new oil wells has risen rather consistently from a low of 70 bbl. to an all-time high of about 512 bbl. in 1930. The average daily production of all operating oil wells has fluctuated between 4 and 6 bbl. to the well. Production withdrawals in 1930 have been estimated at 42,729,085 bbl., an amount only slightly less than the volume produced in the peak year of 1918. The wells of 1918 produced without restriction, whereas those of 1930 were partially curtailed. Consequently, the 1930 potentialities exceeded those of the peak year 1918. The potentialities of Kansas have increased from year to year through the past decade. Today the geological situation warrants the forecast that Kansas in the decade 1930 to 1939 will equal if not exceed the average daily withdrawals of the decade 1920 to 1929. This outlook predicts an output of 365 million bbl. of oil for the decade 1930 to 1939. If realized, the grand total output of 1922 to 1939 will exceed the forecast of the U. S. Geological Survey by about 40 per cent., in a period of 18 years. And in 1939 the potentialities of the State of Kansas will not have been completely exploited, whereas the U. S. Geological Survey estimate of total future recoverable oil reserves was placed at 425 million barrels.

Completions.—Well completions dropped to a new low level in 1930. Out of 991 completions 406 were oil wells, 165 were gas wells and 419 were dry holes. Statistics show an increase in the percentage of dry holes drilled through the years 1920 to 1929. For this decade the percentages range from 21.8 to 42.8, with an average of 34.1. In 1930 the percentage was 42.2. It would appear that production must henceforth bear a much greater charge for dry holes than it has heretofore.

TABLE 1.—*Kansas Oil Production Statistics*

Year or Decade	Oil Wells Completed	Oil Wells Producing at End of Year	New Production for Year or Decade (Bbl.)	Average Daily Withdrawals, Bbl.	Total Production for Year or Decade, Bbl.	Value of Production, Thousands of Dollars
1890–1899				1,214	443,229	
1900–1909				4,875	17,794,794	
1910–1919	16,616			37,973	138,602,414	
1920–1929	10,287		1,252,516	99,272	362,340,969	690,184
1926	1,458	19,230	173,664	113,278	41,498,000	93,800
1927	658	19,600	98,253	114,977	41,069,000	58,300
1928	587	19,800	101,043	105,742	38,596,000	52,500
1929	553	20,080	165,611	117,290	42,813,000	62,510
1930	406	20,285	207,853	117,065	42,729,085	47,002

Constructive cooperation must prevail among producers to raise posted market prices for crude oil to levels that will continue to encourage wildcat prospecting. The number of operating oil wells in the state has increased about 34 per cent. in the past 10 years. Wildcat prospecting has increased, both in the number of wells drilled and in total footage. The average depth of wildcat test wells has increased to about 3600 ft., not by reaching for lower objectives, but because of the greater depths at which they occur westward in the territory now active. Small operators continue to be active in conducting wildcat explorations. Interests can be obtained by the small operator in many of the lease blocks owned by major concerns by drilling a test well. Acreage contributions are frequently augmented by material or cash.

TABLE 2.—*Kansas Development Statistics*

Year or Decade	Total Completions	Completed Oil Wells	Completed Gas Wells[a]	Dry Holes
1900–1909			2,829	
1910–1919	24,395	16,616	4,278	3,501
1920–1929	16,576	10,287	921	5,368
1926	2,338	1,458	96	784
1927	1,333	658	79	569
1928	1,157	587	115	455
1929	1,058	553	52	453
1930	991	401	165	419

[a] These statistics are based on operators' reports to bureaus of the U. S. Department of the Interior. They suggest trends rather than actual facts, and in the case of gas well completions are incomplete by at least several hundred per cent.

Production Curtailment.—The production of certain western flush oil pools was curtailed in 1929. Proration in increasing percentages was applied to all flush production west of the Nemaha Range through the year 1930. These measures were necessary in view of declining market outlets and inadequate pipe line facilities. A few scattered wildcat discoveries in extreme western parts of the producing territory are without any outlet. In these cases the extent of productive lands must be established with the return of normal business conditions before outlets are constructed. Areas east of the Nemaha Range, comprising the old producing territory, have not been disturbed. On Jan. 1, 1931, the Prairie Oil and Gas Co. will withdraw as a purchaser of crude oil. In the western territory this withdrawal may further increase production curtailment, but the abandoned connections will be acquired by other pipe line companies. In the eastern territory, however, the withdrawal of the Prairie will create a serious condition. About 14,000 stripper wells, with a daily production of 10,000 bbl., will have no outlet. These wells

will be abandoned unless the Prairie shortly resumes purchases or the producers organize a cooperative to purchase and gather the oil, transmit it through lines leased from the Prairie, and sell it to refiners with whom it may contract.

There is little likelihood that proration percentages will be increased to permit increased withdrawals at the wells. If the industry is reasonably safe in estimating an adequate steady supply of crude oil for the next five years, present surface storage is excessive and unnecessary. If the storage of crude oil is excessive it can only be corrected by increasing withdrawals from storage at the expense of current well production. Such an interpretation would necessitate further reductions in the percentage of oil withdrawn at the wells throughout 1931, and perhaps for several years in addition.

Production Potentials.—Actual withdrawals at the wells was 113,940 bbl. per day for the week ending Jan. 4, 1930. A high of 134,920 bbl. was set for the week ending May 31, and the latest low was reached in the week ending December 6, when 104,940 bbl. were withdrawn. The potential output of the state at this last date was placed at 214,000 bbl. daily. According to this estimate approximately 110,000 bbl. of crude oil is being withheld from the market. Much if not all of this potential production is flush, subject to a rapid drop-off at a rate of at least 10 per cent. a month for the first six months of unrestricted flow. Since these potential oil production estimates are at best but guesses they must be discounted. By applying a reasonable discount factor and introducing the decline factor it is not likely that Kansas could produce to exceed an average of 150,000 bbl. per day throughout 1931. If stocks of surface storage were at lower volumes and the oil producer converted to regulated withdrawals at the wells, the immediate posted price outlook would be bright and satisfactory.

New Discoveries of 1930

From time to time wildcatting labors are rewarded by new discoveries. The factors governing the occurrence of oil fields are debatable subjects. Many of the critical data delineating oil fields are concealed from observation or subject to numerous interpretations. Consequently the prizes fall most unexpectedly to any operator. Of late, however, the prizes fall most frequently to those who apply technical analysis. This has been the case in the actively exploited areas of central and western Kansas. Notwithstanding a situation of overproduction, excessive surface storage and declining production withdrawals at the wells, there was considerable prospecting for oil in Kansas during 1930. Many wildcat tests were drilled. Some of these were justified by expiring leases; some were drilled to prove or condemn large lease blocks carrying high rental charges;

others were motivated by a desire of operators to acquire additional supplies for their refinery needs, or to improve their production status for valuation purposes preparatory to prospective mergers. The most active counties were McPherson, Rice, Russell, Reno, Kingman and Stafford.

Although there is little restriction on wildcat drilling at this time it is not likely that many new pools will be opened in Kansas during 1931. Major operators owning a majority of the large leasehold blocks scattered through central and western Kansas have shown no inclination to encourage new discoveries, unless compelled to do so by expiring leases or in an effort to reduce heavy rental expenditures. Many of the major operators are offering their blocks for testing, but the individual wildcatter cannot find adequate support. As a matter of fact, wildcat explorations and leasehold speculations flourish only when they are supported by capital funds provided by the major concerns.

Sedgwick County.—The Eastborough pool, on the eastern edge of the city of Wichita, may properly be considered a new development of 1930. Two wells were completed during 1929 in the "chat" for small initial production. Since "chat" production is commonly erratic and not especially significant these completions aroused no general interest, but the completion of a third well in the same objective for 60 bbl. per hour on June 13 did attract attention and stimulate activity. Immediate production outlets to near-by refineries in the city of Wichita encouraged unregulated development. Completions were rapidly effected and by September 15 the potential output reached 7000 bbl. per day from 13 "chat" and 2 Ordovician wells. For the same week withdrawals at the wells averaged 5500 bbl. per day. The discovery of oil in Ordovician objectives acted as a further stimulant, and 31 wells had been completed by December 11, with an estimated potential production of 25,000 bbl. per day. In the meantime pipe line withdrawals increased, and on the same date runs were about 14,000 bbl. per day. However, some of the older wells are still without pipe line connections.

Of 38 completions in the pool, 31 are oil wells and 7 are dry holes. There are 6 test wells drilling. In the outlying territory 8 test wells have been commenced; some of these have been abandoned as dry holes and others are still drilling. The extent of production has been defined on the east, south and west flanks of the fold, which is a northeast-southwest trending anticline. The production occurs in the "chat" of Mississippian age, and in the Misner, Viola and Simpson beds of Ordovician age. Initial "chat" production ranges from 35 to 2500 bbl. per day from depths of 2925 to 3000 ft. The Ordovician objectives are found at depths ranging from 3242 to 3275 ft. The pool is about two miles long in a north-south direction, and one mile from east to west. More of its type will be discovered in Sedgwick County.

Scattered Wildcats.—Although scattered wildcat prospecting was conducted on a smaller scale than formerly there were a number of discoveries. The true significance of these discoveries will not be known until close-in locations have been drilled. They do, however, increase the importance of central and western Kansas as potential oil territory.

Barton County became the thirty-ninth county of Kansas to produce oil in commercial quantities when the Prairie Oil and Gas Co. encountered oil at its Davidson No. 1, on March 25. This well gaged 200 bbl. per day, but has been shut in on account of its isolated location. Production occurs in the "siliceous lime" of Ordovician age at 3314 to 3340 ft. An offset well was completed in December, production status unknown. These wells are in sec. 4, T. 16 S., R. 11 W. There are two other operations in the county temporarily shut down.

Ellsworth County entered the ranks of oil-producing counties with the completion of Heiken No. 1, by Slick et al. The well is located in sec. 25, T. 17 S., R. 10 W., in the midst of a 16,600-acre block covering a structure delineated by a core drill. Production, 1500 bbl. initial, occurs in the "siliceous lime" at a depth of 3221 to 3243 ft. Four other wells are drilling in the county. The Heicken test encountered 7,000,000 cu. ft. of gas in the Lansing formation at a depth of 2980 to 2991 ft., suggesting that this county has natural gas potentialities.

McPherson County witnessed a rather active wildcat drilling campaign, induced partly by expiring leases and the phenomenal developments in the Voshell pool. Strictly wildcat tests afforded no new discoveries in this county, but semiwildcat locations extended many of the established pools for considerable distances. These will be discussed under the grouping of the old fields.

Reno County appears to have a second potential oil field. In July Tatlock et al. completed their Tonn No. 1, for an estimated production of 300 bbl. from the "chat" at 3606 to 3611 ft. The well is in sec. 17, T. 25 S., R. 4 W. All other operations in the county are either dry and abandoned or drilling.

Rice County operations were active in 1930, and as a result a third potential oil field area has been discovered. Tatlock and others completed their Ploog No. 1 in November for an estimated output of 2000 bbl. from the siliceous lime at 3252 to 3253 ft. The well is in sec. 33, T. 18 S., T. 9 W.

Rooks County reports a completion that carries oil production about 20 miles farther west in this county. The well is Boysen et al. on the Siver land, in sec. 21, T. 8 S., R. 19 W. The well flowed 301 bbl. of low-gravity oil from the "conglomerate" zone at 3442 to 3445 feet.

Russell County had a number of wildcat completions, several of which afforded production. These discoveries are on minor structures that are superimposed on the larger egional form—the north central

Kansas uplift. The pools, when developed, are apt to be small and similar to the Gorham field rather than the Fairport district. The Austin Oil Co. has a well on the F. Rockefeller ranch in sec. 6, T. 13 S., R. 12 W., estimated good for 125 bbl. initial from the "Oswald lime" series at 3045 ft. The oil tested 40.8° gravity. Surface and subsurface structure do not suggest another Fairport field in this locality. The Empire Oil and Refining Co. discovered oil about three miles east of the Gorham field at its Dillner No. 1, in sec. 36, T. 13 S., R. 15 W. This well was completed in the Gorham objective at a depth of 3309 ft. for 130 bbl. An offset well by the same company in sec. 35 has been completed for 220 bbl. at 3308 to 3313 ft. E. W. Marland Oil Co. completed its Gideon No. 1 for 180 bbl. at 3325 ft. in the Gorham pay zone. This is an isolated well lying northwest of the Ochs area, in sec. 8, T. 15 S., R. 14 W.

Stafford County has been added to the list of Kansas oil-producing counties. The Midwest Exploration Co. completed Richardson No. 36, in sec. 36, T. 22 S., R. 12 W., in the "conglomerate" zone at 3599 ft. The well had 5,000,000 cu. ft. of gas in a shallow objective, and flowed 320 bbl. of 42° gravity oil in the first 6 hr. after completion. It is an important discovery from which an extensive field may develop.

Activity in Areas Discovered Previous to 1930

The production position of Kansas, both actual and potential throughout 1930, rests largely on the rapid follow-up of the 1929 discoveries. Activity centered in McPherson and Sedgwick counties, with 17 operations active in the former county and 21 active in the latter county on Dec. 5, 1930. Total operations in the state on this last date were 117, with Greenwood and Cowley counties taking third and fourth rank respectively.

McPherson County.—In the first six months of 1930 completions amounted to 107, in comparison with 6 for the same period of 1929. The initial production of 76 new oil wells amounted to 89,229 bbl. for the same period of 1930, and 510 bbl. from two oil wells in the first six months of 1929. Although drilling was largely confined to the development of areas discovered in 1929, a number of wildcat locations were tested, but without effecting a single new discovery. Lower producing objectives were discovered beneath shallower objectives, and a number of semiwildcat locations established important extensions to producing areas. There are now four oil-producing areas in the county.

Voshell field was discovered in August, 1929. The discovery well produced from the Viola lime of Ordovician age. Subsequent completions of 1929 found oil in commercial amounts in the "chat" of Mississippian age, and in the Misner and Wilcox sand objectives. Production

declined rapidly through the first quarter of 1930, and water encroached in increasing amounts. This situation led to deeper drilling, and in March the Derby Oil Co. discovered oil in the "Siliceous lime" at its Stuckey No. 8, in sec. 9, T. 21 S., R. 3 W. On the swab this well gaged 2000 bbl. initial in 24 hr. from a depth of 3415 ft. Other producing wells were rapidly deepened, and in May potential production reached 60,000 bbl. per day from 70 wells, with pipe line withdrawals at 21,000 bbl. per day. Later in the year estimated potential output rose to about 82,000 bbl. daily, withdrawals were set at 8 per cent. of the potential, and pipe line runs averaged about 6500 bbl. per day. In December permisable withdrawals were increased to about 19 per cent. of the potential, and pipe line runs to 13,300 bbl. daily. The field is now about 4 miles long in a north-south direction, and about ¾ mile from east to west at its greatest width. Producing limits of the field have been defined, but the productive area has not been fully developed. There have been 94 completions in the field, the largest of which had an initial production of 2656 bbl. per day. The field probably could sustain an average daily pipe line withdrawal of 25,000 bbl. through 1931.

Ritz field affords both oil and gas. There were seven oil wells and one gas well at the end of 1929 producing from the "chat." The discovery well was drilled in sec. 12, T. 20 S., R. 2 W. Subsequent drilling, close-in and semiwildcat locations, have extended the producing area into parts of four townships, so that the field now has a length of about 3 miles in a northeast-southwest direction and about 1 mile at its greatest width. There are 16 "chat" wells and 2 Viola lime wells, from which about 5500 bbl. of oil are being withdrawn each day by pipe lines. Outstanding developments of 1930 were the completion of a number of wells with large initial flows and the discovery of oil in the Viola. The Shell Petroleum Corpn. completed its Miller No. 1, in sec. 1, T. 20 S., R. 2 W., with an output of 2600 bbl. in 4 hr. under a 200-lb. back-pressure. This well has produced as much as 5128 bbl. of oil in one day. Another "chat" well, The Texas Company's No. 3 Munn, in sec. 12, T. 20 S., R. 2 W., flowed 3365 bbl. in the first 24 hr. from a depth of 2920 to 2982 ft. In November the Mid-Kansas Oil and Gas Co. discovered oil in the Viola lime at its Garrett No. 1, in sec. 30, T. 19 S., R. 1 W. This well, an Ordovician discovery for the field, gaged 3324 bbl. during its first 24-hr. test from the pay at 3407 to 3414 ft. An offset well has been completed by W. C. McBride Inc., in the same section, for an initial swab output of 2054 bbl. at 3414 to 3421 ft. The oil tests 37.5° gravity at 68°. Approximately 1,555,361 bbl. of oil have been run by pipe lines from this field, at the end of 1930. The field is but partly delineated. It should be intensively prospected in 1931, and should have no difficulty in maintaining current withdrawals throughout the coming year. Potentials of the Ritz and Voshell fields will enable McPherson County to

maintain the position it attained in 1930 throughout 1931. In the first half of 1930 the initial production of 95 oil wells in the county amounted to 100,876 bbl., an average of 1062 bbl. to the well. For the same period 2,703,513 bbl. of oil were run from the county.

Decker pool entered the list of oil-producing areas in 1930. The Mid-Kansas Oil and Gas Company's Pitts No. 1, in sec. 8, T. 19 S., R. 2 W., was completed in the "chat" for 400 bbl. at 2995 ft. Another, McPherson and Shell on the Robinson land, in sec. 10, T. 19 S., R. 2 W., reported 190 bbl. from the "chat" at a total depth of 2,957 feet.

Rice County.—There are two oil-bearing areas in this county, commonly considered to offer good prospects for additional discoveries. Current wildcat tests have been failures, but the results cannot be considered significant for their locations are widely scattered. Discoveries in this county, as elsewhere in western Kansas localities, have been effected by testing promising structures.

Schurr pool was discovered in 1929 by a test well drilled to the "chat" in sec. 21, T. 20 S., R. 10 W., to a depth of 3289 ft. The well produced 240 bbl. of 52° gravity oil for the first 24 hr. Failing to secure production in the same objective the Producers and Refiners Corpn. drilled on to the "Siliceous lime," where at 3303 ft. the well flowed 430 bbl. in 19 hr. Five wells were completed in the first half of 1930. Withdrawals from all wells were restricted to 250 bbl. daily until August 1, when the market was discontinued. A pipe line outlet was completed in December, but as this purchaser withdraws on Jan. 1, 1931, the producing wells will probably remain shut in, and little if any development will be undertaken. Nine oil wells have been completed, and two test wells are shut down near the pay. Potential production is estimated at 12,000 bbl. per day.

Welch pool, discovered in 1924 and producing from the "chat," had an important extension. The Hipple and Roger's No. 1 Rainey, in the northeast corner NW. ¼. SE. ¼ of sec. 3, T. 21 S., R. 6 W., flowed 1450 bbl. from the "chat" in 18 hr. Miller No. 2, of the Independent Oil and Gas Co., completed in 1927, average 950 bbl. per day for the first year.

Russell County.—Current developments threaten to again bring general interest into this county, which is largely responsible for the original play in western Kansas. The axis of the north central Kansas uplift passes through this county. On the broad arch of this major uplift are a number of scattered oil pools producing from three objectives, the Oswald, "Conglomerate" or Gorham, and the "Siliceous lime." Most significant were the new developments in the Sellens area, T. 15 S., R. 13 W., and in the Ochs area of T. 15 S., R. 14 W. Ten oil wells, producing from three objectives, are scattered in a narrow northwest-southeast belt through these two townships for a distance of 11 miles.

These wells occur in four groups separated by distances of 3 to 4 miles, without intervening dry holes. They may be the forerunners of separate pools, or they may be extended into one continuous field. Four important producers were completed this year in this district. In July the Prairie Oil and Gas Co. obtained a 20-bbl. well at 3324 ft. in sec. 23, T. 15 S., R. 13 W., on the Berrick land. On November 1, the Signal Oil Company's Sellens No. 1, in sec. 25, T. 15 S., R. 13 W., swabbed 426 bbl. from the conglomerate zone at 3249 ft. in the first 12 hr. On December 17 the same concern, on the Rude lease in sec. 28, T. 15 S., R. 13 W., swabbed 20 bbl. an hour from the Oswald zone at 3175 ft. To the west, in sec. 8, T. 15 S., R. 14 W., E. W. Marland's Gideon No. 1 made 180 bbl. from a depth of 3325 ft. Attractive offset wells were completed around the Ochs discovery well. This county is likely to be the most active of all western Kansas counties next year.

Sedgwick County.—The county is still a major oil-producing center of Kansas. In 1930 its combined output increased about 1,000,000 bbl. over that of 1929, bringing the cumulative production as of Dec. 31, 1930 to approximately 18,091,945 bbl. The daily average production of the three defined pools —Wright, Greenwich and Robbins—and of the scattered areas declined through 1930, but the county retained its rank of second place among the oil-producing counties of Kansas. There was comparatively little activity in the county except in the Eastborough area. The potentialities of the county, however, have not been exhausted. Permitted to produce without restraint, Sedgwick County probably would have passed over Butler County and into first place this year.

Eastern Kansas Counties.—The production situation in eastern counties—Nemaha ridge and eastward—is unchanged. Production in general declined, operations were fewer in number and no important discoveries were made. Greenwood County led in the volume of initial production from new completions; Butler County took second position. Oil properties produced without restraint, but the withdrawal of an important crude-oil purchaser on Jan. 1, 1931, will create a serious situation in the counties east and south of Greenwood County. The entire territory of eastern Kansas has been repeatedly combed for structural folds worth prospecting. Few of these structural discoveries have afforded production of late. Assured market outlets and resumption of the normal amount of prospecting and the resulting new supplies in the eastern territory would do little more than retard the slow and normal decline of settled production. Operations are conducted largely by local *entrepreneurs,* who occasionally open small pools or extensions in the old producing areas. Active explorations have passed into the western territory and the remaining interest lies largely in the discovery of natural gas supply for local markets.

Butler County, with its settled production, leads all counties of the state in output, contributing about 9,000,000 bbl. of oil during the year. Production of the Towanda, Fox-Bush, Leon-Weaver, Douglas, Keighly and Benton pools declined throughout the year in accordance with normal depletion. New completions and improved operations either maintained output or increased it slightly in 11 districts. There were a number of wildcat completions, but these were either dry or extremely small wells scarcely commercial, and therefore not significant. This county has been intensively prospected. Its potentialities are now restricted to the discovery of "shoestring" sands and very small pools in Ordovician objectives. Future output of the county will probably decline slowly, interrupted at times by new developments.

Greenwood County, which was the center of activity several years past, was comparatively quiet during 1930. Oil properties produced without restraint and contributed about 7,250,000 bbl. during the year. New completions failed to stabilize output and production dropped slowly through the year. Operations in the Hamilton district resulted in the discovery of additional links to the Edwards Extension "shoestring," and in carrying the trend to sec. 25, T. 24 S., R. 12 E. Important wells were: Prairie Oil and Gas Co. No. 1 Moran in sec. 16, T. 24 S., R. 12 E., completed for 75 bbl. in the Bartlesville sand at 1603 ft., and the Derby Oil and Refining Co. Beavers No. 1, in sec. 25, T. 24 S., R. 12 E., with an initial production of 100 bbl. from the Bartlesville sand at 1657 ft. Apparently, the Edwards Extension pool will be carried southeastward through the Patterson pool and across T. 24 S., R. 12 E., towards the village of Quincy. The potentialities of this county have not been exhausted. Closely held leases rather than economic conditions retard new development work.

Sumner County has lost its attractiveness for the time being. Offset completions in the Peasel area of T. 31 S., R. 1 W., were mediocre. In the State Line pool the Gypsy Oil Co. reported an initial production of 1548 bbl. from the Wilcox sand at 4770 to 4773 ft. at its Enderude No. 2, in sec. 16, T. 35 S., R. 2 W. Potentialities of the county have not been exhausted. An important discovery would attract wide attention and induce much wildcat drilling.

The Natural-gas Situation

The mobility and efficiency of natural gas as a fuel, new concepts of line construction and transmission distances, and the gradual realization that the industry is neither short-lived nor of local self-sufficiency but national in scope, have made for a substantial growth of an important industry. Every year vast potential areas are added to the whole of the natural-gas lands in continental North America. Heretofore, proximity of supply to markets determined the feasibility of projected transmission

systems. But now concentration of capital in supergas systems, patterned after the operating structure of the electric power industry, brings the most distant sources of natural-gas supply within economic transmission range of adequate markets.

Production statistics for the state begin with the year 1897, when 10 operators with 90 wells sold gas to the value of $105,700. At that time there were 20 industrial consumers in the state and 3956 domestic

TABLE 3.—*Kansas Natural-gas Statistics*

Year or Decade	Gas Wells Completed	Gas Produced, Million Cu. Ft.	Gas Consumed, Million Cu. Ft.
1900–1909	2,829	514,674	[a]
1910–1919	4,278	298,930	[a]
1920–1929	921	305,429	475,036
1926	96	38,095	61,142
1927	79	42,647	66,618
1928	115	45,644	72,671
1929	52	38,469	75,476
1930	165		

[a] Statistics are not available. Consumption of Missouri markets included with those of Kansas for these decades.

TABLE 4.—*Statistics on Natural-gas Gasoline*

Year or Decade	Number of Plants	Quantity Produced, Gal.
1916–1919	1–13	7,063,706
1920–1929	8–28	182,828,077
1920	10	4,330,748
1921	11	3,587,329
1922	8	2,856,000
1923	13	8,775,000
1924	14	11,658,000
1925	15	19,592,000
1926	21	25,369,000
1927	24	36,095,000
1928	28	36,765,000
1929	27	33,800,000
1930	24	32,400,000

stoves were provided with gas as fuel. Consumption and the number of customers increased rapidly, always exceeding internal production, and the state has always been dependent upon the gas fields of Oklahoma for its supply. The reserves of Oklahoma have been augmented recently by immense supplies in the Texas Panhandle and in southwestern Kansas. In addition, the scattered natural-gas discoveries of central and western Kansas are suggestive of further important reserves in that territory.

Eastern Kansas still affords natural gas in important volumes from numerous objectives in the Pennsylvanian and uppermost Mississippian sections. Reservoirs are found in sandstones, limestones and shales. Although explorations drop to new low levels with each succeeding year, new discoveries are now and then effected, especially in the shoestring sands of northeastern Kansas and in the shale areas of eastern and southeastern Kansas. The resultant contributions of these discoveries are insignificant; they are a factor in near-by local markets for a short time, whereupon these markets become dependent upon more distant and stable supplies. Year after year the industry has been considered a short-life enterprise. In a local sense this has been and is true but from a national point of view this concept is not true, as evidenced by enlarging reserves that now support a national consumption that has grown fourfold in 20 years, and twofold in the last 6 years.

Kansas, west of the Nemaha Range, has this year assured the state that it contains reserves and current output far in excess of current consumption for the first time in its history. And for the first time in its history the state will appear on the list of states exporting large quantities of natural gas to markets in near-by and distant states, through three supergas transmission systems recently completed or now under construction. These systems will induce further prospecting in the territories they traverse, while those long established in the eastern localities will encourage continued exploration to offset the normal decline of the old gas fields. In Kansas the industry faces years of steady growth and production in excess of 100 billion cu. ft. per year. Gas-producing areas are scattered throughout the state except in extreme northern parts, and there geologic conditions do not preclude their presence. With new market outlets, exploration for natural gas will extend across the state, many discoveries will be made, and a large temporary surplus may develop. The fact that invested capital is returned at a slow rate, except in cases of strategically located production, may act as a retardant. The natural-gas industry, not unlike other industries, has its overproduction problems, necessitating reduced and inadequate withdrawals at the wells. The rapid expansion of supergas transmission systems may readily overstimulate exploitation of supply, but at the same time these systems will create consumption levels difficult to supply in future years except by the addition of by-product gases from retorted coals.

Current Developments

Current developments have enabled the state to break all previous production records and to engage in the interstate transmission of natural gas. The outstanding natural-gas development of all time in Kansas was the rapid prospecting of potential gas lands in southwestern parts of

the state, which established commercial production over about 350,000 acres, proved the potentialities of about 500,000 acres in addition, and created at least 200,000 acres more of prospective territory.

Southwestern Kansas.—Natural gas was discovered in the Liberal district of Seward County in 1922. In 1927 a gas well was completed in the Hugoton district of Stevens County, making five completions for the territory. Although the territory was considered to contain potential natural-gas lands, interests lay dormant until 1928, when leases were acquired on a large scale preparatory to development work for a projected gas pipe line system. Leasehold acquisitions continued through 1929, and in 1930 drilling operations spread out rapidly over large parts of Stevens and Morton Counties and into Grant County. Future operations may advance the area of contiguous gas production northward into Stanton County, eastward to and beyond the Liberal area of Seward County, and farther westward in Morton County; perhaps across this county into eastern localities of the State of Colorado.

Production is found in a zone of dolomitic limestones and shales about 300 ft. thick, of Lower Permian age and probably equivalent to the "Big Lime" section of the Amarillo, Texas, territory. Pays are encountered at depths ranging from about 2400 to 3000 ft., and the wells afford initial volumes ranging from 1,000,000 to 14,000,000 cu. ft. of gas per day, with an average of about 6,000,000 cu. ft. to the well for current completions. The virgin reservoir pressure was probably 420 lb. Recoveries should exceed 6,000,000 cu. ft., of gas to the acre, and the territory appears to be capable of providing an ultimate supply of about 5 trillion cubic feet of gas. The wells are commonly drilled to the top of the pay zone with rotary tools and from there completed with standard tools. The cost of a completed well, fully equipped, averages about $27,500. They are usually drilled in the centers of 160-acre tracts. Operations are widely scattered, and it is not likely that all four quarters of a section of land will be developed for a long time, if ever. The accumulation of the gas is anticlinal in a regional sense, apparently trapped by the up-dip termination of porous reservoir rocks.

There are about 118 completions in the territory, comprising Morton, Stevens, Seward and Grant Counties, with an estimated open-flow volume of 642 million cubic feet of gas per day. These gas wells prove an area of at least 350,000 acres, establish the potentialities of an additional 500,000 acres, and extend the borderland areas for at least another 200,000 acres. Significant completions were: McKenna et al. on the Sullivan land in December for 3,500,000 cu. ft. at 2540 to 2715 ft., in sec. 12, T. 29 S., R. 38 W., Grant County; and the Hydraulic Oil Co. No. 1 State Lands in sec. 22, T. 34 S., R. 43 W., Morton County, now plugging back to the gas pay.

Western Kansas.—There are three gas-producing areas in what is commonly designated as western Kansas. The areas are small at this time and scarcely of commercial importance except that they do support near-by markets. Several wells were completed during the year in the Medicine Lodge field of Barber County. Production occurs in the "conglomerate" zone at depths of 4447 to 4650 ft. The initial open-flow volumes of the six producing wells range from 1 to 26 million cubic feet. Accumulation is anticlinal. An extensive field may develop in the Lewis district of Edwards County. The Dixie-Amerada companies completed a gas well in July for 8,000,000 cu. ft. of gas in the "conglomerate" zone at 4960 ft. The well is in sec. 22, T. 25 S., R. 17 W. The Barnsdall Oil Co. encountered 7,000,000 ft. of gas in McCarty No. 1, sec. 31, T. 25 S., R. 17 W. at 4549 ft. This well was later deepened and completed for an oil well. The reservoir pressure of the gas pay was 1350 lb. The Milmac Oil Co. obtained 16.5 million feet of gas at its Mohr No. 1, a test well in sec. 11, T. 18 S., R. 16 W., Rush County. The well was a wildcat location about 8 miles east and slightly south of the Bison area of Rush County, which proved disappointing last year. The .deepest test well in the State of Kansas has been abandoned in the Morrison area of Clark County. It is the No. 2 Morrison of the Watchorn Oil and Gas Co., in sec. 20, T. 32 S., R. 21 W., drilled to a total depth of 6909 ft. A number of scattered test wells in this territory have reported gas showing in the Liberal-Hugoton objective of southwestern Kansas. It would not be surprising if the later objective affords natural gas in commercial quantities on closed anticlinal folds in western Kansas localities.

Central Kansas.—West of the Nemaha Range and east of the north-central Kansas arch lies a territory to which the name "central Kansas" is frequently applied. Scattered about are a number of important commercial gas pools and important showings of gas in wildcat test wells. The gas is produced principally from the "chat," restricted to the upper 50 ft. of Mississippi lime. Accumulation is anticlinal in all cases. Outstanding active gas-producing areas are: McPherson gas field, T. 18 S., R. 2 W., McPherson County, fully developed; the Ritz area, T. 19 S., R. 1 and 2 W., and T. 20 S., R. 1 and 2 W., McPherson County, partly developed; the Decker (Galva) gas field, T. 19 S., R. 2 W., in which additional completions were drilled during 1930 without defining the extent of production; and small pools in Harvey and Marion Counties, fully developed. Gas is also encountered in objectives of Pennsylvanian age through this territory. In the Lipps area of Chase County, production is obtained from sands in the Lawrence formation. The two local areas in T. 30 S., R. 2 W., Sumner County, produce from the Topeka, Howard and Severy formations. Western parts of this territory may afford gas in the Permian objective producing in southwestern Kansas.

There were a number of important gas discoveries in this territory in 1930. Study et al., on the Haury land, sec. 1, T. 23 S., R. 4 W., Reno County, had 22½ million cubic feet of gas in the "chat" at 3333 ft. Derby Oil Co. et al. had 5,000,000 cu. ft. of gas in the Heicken No. 1 well, sec. 1, T. 25 S., R. 10 W., Ellsworth County, at 2980 to 2981 ft. This well, however, was deepened to lower objectives and completed as an oil well. In Rice County, Robertson et al. reported 11 million cubic feet of gas at Cupp No. 1, sec. 22, T. 18 S., R. 9 W., from a Pennsylvanian objective at 2019 to 2021 ft. Trembly No. 1, of the Skelly Oil Co., sec. 30, T. 24 S., R. 7 W., Reno County, reported 2,000,000 cu. ft. of gas. In Kingman County, the Skelly Oil Co. has bradenheaded 10,000,000 cu. ft. of gas from a series of sands found from 2002 to 2144 ft. in its Miles No. 1, sec. 30, T. 27 S., R. 10 W. The production is from Pennsylvanian objectives.

Eastern Kansas.—Shoestring sands and the Oswego shale section have afforded further natural gas production during 1930 in northeastern Kansas localities. Shale gas developments of this territory center largely in Johnson and Miami counties, and the sands in Anderson, Franklin and Linn counties. The current contributions of this territory, together with the old production, cannot supply local needs. There were a few completions but no important discoveries in southeastern Kansas. In this district the natural-gas objectives occur in Pennsylvanian and Mississippian formations. Production is obtained from sandstones, limestones and shales, with "chat" and shale objectives contributing most of the new gas supplies. Eastern Kansas has been combed for natural gas supplies, and while there are areas that have not been adequately tested there is little likelihood that supplies in excess of local needs will be discovered in the future.

Acknowledgments

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Production in Oklahoma during 1930

By Henry A. Ley,* Tulsa, Okla.

(New York Meeting, February, 1931)

Oklahoma produced about 40,000,000 bbl. less crude oil in 1930 than it did in 1929, but developed the largest initial production from current well completions ever recorded in its history. The output of this year would have exceeded all previous years had it not been for state-wide production curtailment. The record initial production of 5,911,982 bbl. from new oil wells completed during the year is accounted for entirely by the rapid development of the Oklahoma City field. Completions declined to the lowest levels since 1909, as a result of a marked reduction in number of dry holes incident to reduced wildcat exploration. Leasing was most active in western and northern counties of the state west of Oklahoma City, but on a much smaller scale than in the preceding year. Geological and geophysical surveys were likewise most active in this western territory. The urge to deeper objectives resulted in the discovery of oil on the Cement fold.

Changing economic conditions have created a distress situation among the marginal operators in northeastern localities of the state. Elsewhere in the state production records and successful exploitation of new supplies have been eclipsed by a new social concept of the industry in accord with natural economic developments. Many of the producers of crude oil have organized for a voluntary stabilization of the industry by regulating the output of wells. To enforce their measures these operators have sought for and secured the support of the state. Consequently, the current position of the crude-oil producer is not unlike that of the natural-gas producer—withdrawal of supplies in accordance with market needs. And while the industry as a whole is artificially stabilized by these measures individual operators and some of the integrated concerns suffer hardships.

Oil Developments and Production

The early operations in Oklahoma were confined to northeastern and eastern localities, beginning in 1885. The first commercial oil wells were completed in 1894, near Chelsea in Craig County, from Cherokee sands in the lower portion of the Pennsylvanian section. Scattered

* Consulting Geologist.

operations in the following years discovered new producing areas. In those days new discoveries seldom influenced land values beyond the township in which the discovery was made, whereas now an entire county and even large sections of a state are immediately affected by a single phenomenal discovery. Until 1912, when the Cushing field was discovered, the Cherokee sands were the most prolific objectives of the state. The Bartlesville sand objective of the Cherokee formation was found at depths of less than 1000 ft. in the pools of Nowata County and about 1300 ft. in the pools of Washington County when general activity commenced in 1904. Depths increased to 1800 ft. with the discovery of the Glenn field in 1906, and to 3000 ft. in 1920 with the discovery of the Burbank field. In 1912 objective depths were carried to 2250 ft. with the discovery of the Cushing field in the Wheeler pay, and to 2600 ft. in 1913 with the discovery of oil in the Bartlesville sand. Shortly thereafter depths were carried to 2800 ft. with the discovery of oil in Ordovician sands. From this time on the Ordovician objectives increased their contribution to the oil output of the state. In reaching for this deeper objective depths increased to 4100 ft. with the discovery of the Seminole City field in 1926, and to 6500 ft. with the discovery of the Oklahoma City field in 1928. For the week ending Dec. 20, 1930, two Ordovician districts—Seminole and Oklahoma City—heavily curtailed produced 237,530 bbl. per day, whereas the remainder of the state produced 224,380 bbl. per day, much of which was withdrawn from Ordovician pays. Today exploration interest centers largely in the discovery of Ordovician fields on large folds in the deeper territory west of Oklahoma City and Seminole. As prospecting advances westward, towards the axis of the Anadarko trough, objective depths will increase, possibly to 10,000 feet.

Production.—Oklahoma produced approximately 215,552,000 bbl. of oil in 1930, or 1.3 per cent. less than in 1929, a decline to the lowest output since 1926. The supply of crude oil was in excess of demand, and until the late months of the year withdrawals from wells were in excess of consumption demands. Prices of crude oil were reduced 17 to 41 c. per barrel on January 16, with price quotations ranging from 66 c. to $1.44 per barrel April 10, quotations were advanced 7 to 14 c. per barrel, but in October were again reduced to a range of $0.65 to $1.07, thereby bringing the average weighted price of crude at the wells to $0.95. Average daily withdrawals in 1930 ranged from 675,285 bbl. during the week ending January 4 to a high of 706,765 bbl. during the following week, a low of 451,520 during the week of December 6, and 461,910 bbl. for the week ending December 20. The average initial production of oil-well completions reached an all-time record of 3004 bbl. for each well. The Proration Committee of Oklahoma estimates potential production of the state as 4,244,299 bbl. as of December 31. Of this amount

798,294 bbl. are based on reliable gages, and 3,446,000 bbl. attributed to the Oklahoma City field by none too satisfactory estimation methods. It has been proposed that withdrawals of crude oil at the wells be reduced to estimated probable demand next year. The probable demand has been tentatively set at 465,000, 469,000 and 470,000 bbl. daily for the months of January, February and March, a total withdrawal from wells of about 42,120,000 bbl., whereas in 1930 during the same period 58,530,530 bbl. were withdrawn. If enforced the new order will reduce output for the first quarter of 1931 to about 28 per cent. less than the same quarter of 1930.

Oklahoma City field produced 17,876,700 bbl. of oil in the first six months of 1930 and 16,488,955 bbl. in the final period of the year—a total of 34,365,655 bbl. or about 16 per cent. of the state's entire output. The *Oil and Gas Journal* quite properly divides the state into three districts for production purposes, Oklahoma City, Seminole-St. Louis and remainder of state. The respective outputs of these districts were 80,485, 157,045, and 224,380 bbl. daily during the week ending December 20.

Completions.—Well completions, 3269 for the current year, were less than in any former year since 1909; oil wells completed sank to the lowest levels since 1904; gas wells to levels of 1916; and dry holes were less in number than in any year since 1915. Table 1 shows the results of exploration in the state of Oklahoma since the discovery of oil. There are approximately 64,950 producing oil wells in the state of Oklahoma, of which about 20,000 are "strippers" with a daily output of about 25,000 bbl. These wells are properly marginal producers until such a time as crude oil commands a price of about $3.50 per barrel and it becomes economical to recover the oil left in the sands by flooding, repressuring and mining. Since production curtailment will continue through 1931, either by state regulation or by restriction of market outlets at spot cash, completions in 1931 will continue to decline. There will be some constructive drilling necessitated by lease terms, and further acquisitions of new leases following current geological investigations.

Import of Statistics

As industry and commerce become more involved and interdependent, production and consumption statistics become invaluable. Yet even today when their importance is commonly appreciated they are neither adequate nor entirely convincing in their import. Table 1 has been prepared by consulting many sources. The data vary according to the source, and are indicators of trends rather than precise records.

Potentialities of the state have increased from year to year by transferring potential districts to producing districts and by reaching to deeper objectives. They have consistently exceeded the common consensus of opinion expressed in forecasts. For example, the State of Oklahoma

TABLE 1.—*Oklahoma Oil Production and Development Statistics*

Year or Decade	Completions	Completed in Decade or Year		Oil Wells Producing at End Decade or Year	New Production for Year or Decade	Average Daily Withdrawals	Total Production for Year or Decade, Bbl.	Value of Production, Thousands of Dollars	Average Cost of Completed Well	Average Depth[a] of Oil Wells, Ft.
		Oil Wells	Gas Wells							
1891–1900						2	7,554			
1901–1910	23,335	19,918	2,477	3,618	1,479,780	59,104	215,729,788	85,903		1,500
									$2,500	
1911–1920	72,469	53,456	13,752	55,700	5,363,276	233,881	853,666,315	1,341,474	26,437	2,750
									35,509	
1921–1930	47,913	28,778	14,141	64,950	16,321,707	535,335	1,953,973,000	3,134,515	83,333	4,750
1926	5,352	3,119	1,735	61,600	1,149,597	490,945	179,195,000	413,900	31,729	4,000
1927	4,513	2,562	1,443	61,750	1,971,081	761,027	277,775,000	397,200	32,173	4,200
1928	3,679	1,961	1,227	62,900	1,016,000	683,720	249,558,000	347,600	45,574	6,000
1929	3,613	1,999	1,245	63,875	1,178,945	698,630	255,004,000	364,650	53,600	6,500
1930	3,269	1,968	939	64,950	5,911,982	590,553	215,552,000	269,440	83,333	6,500

[a] Average depths to lowest important objective of principal flush fields of the current year.

has produced 1,841,339,000 bbl. of oil since the 1922 forecast of the U. S. Geological Survey, which allotted to the entire state a total future recovery of 1,340,000,000 bbl. The output of oil in Oklahoma during the last decade may have reached the climactic position on the production curve. If so, the outputs of future decades are not apt to decline much more rapidly than they rose, certainly not if the production history of Pennsylvania, New York, West Virginia and Ohio are criteria. The geological potentialities of Oklahoma have not been exhausted, and

TABLE 2.—*Production Statistics of Important Oklahoma Oil Fields*

Pool Field	County	Producing Zone	Total Recovery,[a] Bbl.	Acres Producing	Recovery per Acre, Bbl.	Present Status	
						Wells Producing	Withdrawals per Well,[a] Bbl.
Glenn	Creek	Pennsylvanian	204,432,307	27,000	7,572	2,606	2.5
Burbank	Osage-Kay	Burbank	186,000,000	20,810	8,938	2,081	6.4[b]
Cushing	Creek	Pennsylvanian, Ordovician	307,807,771	30,100	10,226	2,380	5.0[b]
Wewoka	Seminole	Pennsylvanian, Ordovician	27,331,241	2,150	12,712	212	18.8[b]
Garber	Garfield	Pennsylvanian, Ordovician	41,591,237	4,000	10,398	712	5.9[b]
Cromwell	Seminole	Pennsylvanian, Ordovician	39,301,971	4,050	9,704	348	12.2[b]
Cement	Caddo	Permian	8,488,118	2,200	3,858	187	16.0
Hewitt	Carter		68,499,703	2,780	24,640	823	6.4[b]
Healdton	Carter		159,075,639	7,250	21,991	1,907	4.8[b]
Tonkawa	Kay-Noble	Pennsylvanian, Ordovician	107,369,867	5,680	18,903	619	6.9[b]
Braman	Kay	Orodovician	12,973,722	1,150	11,281	121	14.9[b]
Roxana	Logan	Wilcox	8,356,814	430	19,343	42	182.0
Okla. City	Oklahoma	Ordovician	43,214,955[b]	6,760	6,392	676	131.0[b]
Bristow	Creek	Pennsylvanian, Ordovician	89,664,186	18,050	4,967	1,115	9.0

[a] As of March 31, 1930 except where noted otherwise.
[b] As of Dec. 31, 1930.

extensive districts are still relatively unexplored. The production outlook is not discouraging even though most of the conspicuous surface folds have been tested. Conservatively evaluated, the factors in production warrant a prediction that the state should produce an average of 500,000 bbl. per day through the next decade, and 200,000 bbl. per day through the succeeding decade of 1940–50—a total of at least 2555 million barrels of oil in 20 years.

Production Proration.—The rapidity of operations in the Seminole district, whereby a daily output of 175,000 bbl. was developed in the

last five months of 1926, provided a supply in excess of pipe line capacity. This production congestion brought about pipe line proration throughout the Seminole district in 1926. The voluntary measures of 1926 were strengthened in the middle of 1927 by proration orders from the Corporation Commission of the State of Oklahoma, but applicable only to the Seminole district. In the late months of 1928 state-wide curtailment was effected by orders of the Corporation Commission. Regulated production withdrawals at the wells have been enforced since 1928. Permissible withdrawals have been consistently reduced in volume until recently when they were stabilized at levels corresponding with consumption. It is not likely that this artificial level will be maintained if the industry seriously intends to reduce surface storage. In October of 1930 the output of all wells producing in excess of 5 bbl. per day was curtailed according to a schedule and by dividing the pools into classes. The allowed production, set by the last orders of 1930, ranges from 18¾ to 50 per cent. of the estimated or actual gaged production per well per lease. Effective Jan. 1, 1931, proration will be applied only to wells producing in excess of 10 bbl. per day.

Strenuous efforts have been made to set aside all production regulation. State regulation of production by proration schedules, in which an attempt is made to provide a market outlet for all producers, may be declared unconstitutional. If so, market outlets for spot cash will probably contract to further embarrass small concerns and individual operators, and economic regulations will replace state regulation to the advantage of the integrated concerns of the industry.

Production Potentials.—The Corporation Commission of the State of Oklahoma has estimated and set the potential output of Oklahoma at 4,244,299 bbl. per day for December, 1930, from which 461,910 bbl. of oil were withdrawn daily during the week ending December 20. There are statistical data to indicate that the Oklahoma City field has reached the zenith of estimated potential output and has made substantial declines from that position which no amount of new completions will ever retrieve. Notwithstanding, the Corporation Commission sets the potential potentialities of the Oklahoma City field at 3,446,000 bbl. for December, 1930, 5,388,298 bbl. for January, 1931, 5,838,804 bbl. for February, and 6,411,-459 bbl. for March.

New Discoveries

There were no wildcat discoveries of major significance during the current year. There were scattered discoveries that future developments may expand into pools of minor import. Generally exploration extended former producing areas and discovered oil in lower stratigraphic objectives of producing pools. Prospecting was most active in the western half of the state. The fact that the number of dry holes declined to the

lowest levels in 15 years is sufficient proof that the price of crude oil, lack of support by major operators and proration have effectively curtailed prospecting. Further price reductions, rather than drilling restriction measures by the state, will retard new discoveries in the coming year.

South Earlsboro Pool.—The Amerada and Dixie companies opened the South Earlsboro pool in February at their Grounds No. 1, sec. 22, T. 9 N., R. 5 E. The well made 7364 bbl. initial. A later completion by the same companies in sec. 23, T. 9 N., R. 5 E. made 11,450 bbl. from the Wilcox sand at 4210 ft. A shot increased the output to 14,800 bbl. Development soon delineated a small producing area from which 27 wells produced 2,972,161 bbl. of oil in 1930; an average of 110,080 bbl. to the well. At the end of the year the pool had an estimated potential production of 9400 bbl. daily, from which about 7500 bbl. daily were being withdrawn. In less than one year this spot has afforded a recovery of 11,000 bbl. to the acre, notwithstanding severe proration curtailment.

Wanette Pool.—The Wanette pool, also known as the West Asher pool, is in Pottawatomie County. The discovery well was completed in February by the Payne Drilling Co. et al. in sec. 22, T. 6 N., R. 3 E. Plugged back from a hole full of water in the Simpson to a sand at 3502 to 3512, the well produced 720 bbl. initial. Development soon established the importance of this area, which had an estimated potential output of 53,777 bbl. at the close of the year. Fifty wells produced 1,469,424 bbl. in 1930, a recovery of 2939 bbl. to the acre. Current withdrawals are 7300 bbl. daily, or about 15 per cent. of the potential, whereas earlier in the year it was set at 25 per cent.

Wewoka Townsite.—Operations were revived in the Wewoka district when the Deep Rock Oil Corpn. completed a Wilcox sand well for about 1600 bbl. on the air-gas lift. The well is in sec. 30. T. 8 N., R. 8 E. The west offset to the discovery well produced 1845 bbl. in 3 hr. from the same objective at 3970 feet. There are six producing wells bottomed in the Wilcox and Cromwell sands, now pinched down to a daily output of 50 bbl. per well. About 121,200 bbl. have been withdrawn from the pool which occurs on a steep fold.

Harper County.—The Sinclair Oil and Gas Co. drilled Howell No. 1, sec. 14, T. 26 N., R. 24 W., to a depth of 8589 ft., the deepest hole of the state. The hole was plugged back to 5350 to 5400 ft. and shot into production. The well produces about 14,000,000 cu. ft. of gas per day and 50 bbl. of gasoline, which is piped 4 miles to a loading rack and shipped by tank car. The drilling of this well revealed an unusual thickness of late Mississippian (Tennesseean) formations heretofore unsuspected in western Oklahoma. This condition is known to extend northward into Clark County, Kansas, and should prevail throughout the deeper parts of the Anadarko basin of western Oklahoma. Production of this well comes from the Tonkawa series.

Oklahoma City District.—Twelve miles north of the Oklahoma City field the Mid-Kansas Oil and Gas Co. et al. completed a wildcat well for 450 bbl. in the Wilcox series at 6697 to 6772 ft. The well is in sec. 32, T. 14 N., R. 3 W., on an anticlinal fold, probably on the Oklahoma City-Garber line of folding. Scattered subsurface data at this time suggest that the producing area will not be extensive.

Garfield County.—In Garfield County, between the Covington and Marshall areas, the Continental Oil Co. et al. obtained 818 bbl. initial after shooting Brown No. 1, sec. 10, T.20 N., R. 4 W. The well made 25,000,000 cu. ft. of gas at 5095 to 5117 ft.; drilled to 5300 ft., flowed 130 bbl.; at 5865 ft. flowed 55 bbl. natural; and after plugging back from 5973 ft. to 5865 ft. and shot made 818 bbl. initial. Subsurface data suggest small producing area of the Lovell type.

Logan County.—Katscher No. 1, a wildcat test, sec. 34, T. 17 N., R. 4 W., drilled by the Eason Oil Co., flowed 842 bbl. in 21 hr. from the Layton sand at 4918 to 4952 ft. The oil tested 46.6° gravity. The well is about 9 miles south and east of the Lovell pool on the Marshall-Lovell-Oklahoma City line of folding. Prospecting this year along this line of folding has resulted in a number of scattered discoveries. Other producing areas should be discovered along this trend, but present data do not indicate pools with the extent of the Oklahoma City field. They are more apt to be of the Lovell type in areal extent.

Developments in Areas Discovered Previous to 1930

Activity centered largely in the Oklahoma City field and in the minor developments of the Seminole district. Three major pools of the state, Oklahoma City, Konawa and Sasakwa, showed increased output. Thirteen other pools showed production losses ranging from about 70,000 bbl. for the year to 3,000,000 bbl., and in the aggregate declined more than 6,000,000 bbl. for the year.

Oklahoma City Field.—The Oklahoma City field was discovered Dec. 4, 1928. There were 68 producing wells at the end of 1929 with an estimated potential output of 450,000 bbl. daily. In 1929 the field produced 8,849,300 bbl. By extremely rapid development 608 producing oil wells were completed in 1930, from which 34,365,655 bbl. of oil were withdrawn, an amount representing about 16 per cent. of the state's entire 1930 output. The producing area should cover about 11,500 acres, of which about 2600 acres lie within the city of Oklahoma City. At the end of 1930 the field had produced a cumulative total of 43,214,955 bbl. or an average of 63,927 bbl. to the well.

The producer and royalty owner received about $1.50 for the oil produced in 1929, or the sum of about $13,273,950. Until Nov. 1, 1930, most of the oil sold at $1.26 per barrel and returned $36,744,120 to the

producer and royalty owner. For the remainder of 1930 the posted price was $1.01 per barrel, with output valued at $5,255,691. For the entire cumulative output of the field operators and royalty owners received about $55,273,761. Of this amount the producer received $48,364,541 and the royalty owners $6,909,220. Assuming that it cost $160,000 to drill and equip the average well exclusive of lease equipment, the development to date has cost $128,160,000 for oil wells and $1,760,000 for dry holes. At an average price of $300 per acre for leaseholds, the oil and gas rights cost $2,670,000. Exclusive of administrative charges, damages, lease equipment, interest, taxes and operating expenses the producers have invested at least $132,590,000, of which at least $84,225,459 must be returned out of future production.

On August 10, the field had an average pressure of 1206 lb., a decline of 45 per cent. from the virgin reservoir pressure of 2200 lb. At that time 221 sand wells were reported to have had an average pressure of 1256 lb., and 138 lime wells an average of 1135 lb. The maximum pressure reported was 1900 lb. and the minimum 300 lb. Air plants cost about $215,000 at Oklahoma City. Theoretically these plants should handle six wells on steady production and 10 when subject to proration. It is reported that air-lift installations have not been satisfactory in this field at this time. If perfected the economic limit for the air-gas lift will be reached when well production declines to 200 to 300 bbl. per day. At that time the well must be put on the pump or abandoned.

The Oklahoma City field lies on an asymmetric surface anticline of at least 125 ft. of closure, partly recognized in 1917 but not correctly delineated until 1926. Beds at the surface are members of the Enid group of the Permian system. Beneath them are 1300 to 2300 ft. of Permian formations and about 4000 ft. of Pennsylvanian formations. Basal members of the Pennsylvanian section rest on a truncated and faulted Ordovician fold bringing the Arbuckle into contact with the Cherokee at the apex of the fold. Westward the Cherokee rests successively on undifferentiated Simpson sands, the Wilcox and Simpson-Viola limes. Five Pennsylvanian sand series have afforded natural gas in commercial volumes and showings of oil but have not been explored for production in the rush to complete wells in the more prolific Ordovician pays. The phenomenal producers are completed in the Wilcox, Simpson or Arbuckle objectives of Ordovician age. Elsewhere in Oklahoma the Arbuckle produces oil only in the upper 50 ft. of the section, but at Oklahoma City output has been increased by drilling as far as 500 ft. below the upper surface of the formation. The Arbuckle produces over an area of about 2240 acres, and the Ordovician sands over an area of at least 9200 acres, of which about 2600 acres lie under the city proper. There is a water menace, but it is no more serious than in other oil fields. More serious is the method of withdrawing the oil, which has unduly depleted gas pres-

sures and will reduce the normal flowing recovery. The wells are drilled and completed with heavy-duty rotaries.

Greater Seminole.—By common usage there are 12 pools in this district. The district was discovered in 1926 and produces largely from Ordovician sands. Accumulation is anticlinal, restricted to scattered closed folds superimposed on a broad structural plateau. Rapid exploration and application of the air-lift pushed production of the district to a peak in 1927. By years the output is as follows: 1926, 10,917,225 bbl.; 1927, 136,104,000 bbl.; 1928, 127,656,000 bbl.; 1929, 128,379,717 bbl.; and 1930, 81,074,483 bbl. from about 2193 wells.

Two new pools, previously described, were discovered in 1930; namely, South Earlsboro and Wanette or West Asher. There were minor extensions to some of the producing pools, and some of the older producing wells were drilled farther into the Ordovician sand section. The Gypsy Oil Co. completed the deepest well in the district in sec. 6, T. 8 N., R. 6 E. The Arbuckle lime was found at 5840 ft., but the hole was carried to 6405 ft. before abandonment. In December a survey of the district revealed that about 3 per cent. of the producing wells were flowing, 71 per cent. were pumping, 14 per cent. were on air-lift, 12 per cent. were off production and 46 per cent. were making water.

Sasakwa Pool.—Sasakwa pool, more commonly carried as the Signal Hill pool, was discovered in June, 1929. It is in the northwestern part of T. 6 N., R. 8 E. but extends into T. 7 E., Seminole and Hughes counties. Forty wells, completed in Ordovician sands, produced 1,600,000 bbl. in 1929, while 50 wells in 1930 produced 3,120,381 bbl., a total of 4,720,381 bbl. The recovery to date is about 9500 bbl. to the acre. The estimated potential output of the pool is now about 9000 bbl. a day.

Konawa Pool.—This pool is located in T. 6 N., R. 6 E., Seminole County. It was discovered in November, 1929. Development was rapid with 3 wells completed in 1929 and 105 wells in 1930. As late as November 10, the Magnolia Petroleum Co. completed a well in sec. 29, for 3212 bbl. in 12 hr. from a stray sand at 2690 to 2776 ft. Cumulative production from 108 wells, almost entirely the output of 1930, was 5,049,103 bbl. as of December 31, a recovery of 4675 bbl. to the acre. The producing sand is sometimes designated Cromwell, but is more properly described as a sand series in the lower Pennsylvanian system.

Carr City Pool.—There were additional developments in this pool, which is a member of the Greater Seminole group. There are now 75 producing wells, compared with 57 at the end of 1929. Cumulative production from the Wilcox is 7,581,016 bbl., of which 3,160,823 bbl. was produced in 1930. Recovery to date is about 10,000 bbl. to the acre.

Cement Field.—The Cement field is in T. 5 and 6 N., R. 9 and 10 W., Caddo County. A well was completed in 1916 for 500,000 cu. ft. of gas at 1415 ft. A test well encountered oil in 1917 at 1700 ft. Later

in the same year a gas well was completed for 35,000,000 cu. ft. of gas at a depth of 2340 ft. Subsequent wells, on or near the axis of the anticline, produced oil in amounts estimated from 50 to 150 bbl. All of this production was found in erratic sands of the Permian system. In 1930, a number of deep test wells were drilled, affording both oil and gas in sands of the Pennsylvanian system. The Noble-Olsen Drilling Co. deepened its Rowe No. 2, sec. 36, T. 6 N., R. 10 W., to 3397 ft. At this depth the well flowed 336 bbl. in 12 hr. The Mid-Kansas Oil and Gas Co., Wade No. 9, sec. 2, T. 5 N., R. 9 W., produced 700 bbl. initial from a new pay at 4057 to 4092 ft. The Magnolia Petroleum Co. obtained 51,000,000 cu. ft. of gas at its Sanes No. 3, in sec. 35, T. 6 N., R. 10 W. at a depth of 3406 to 3420 ft. The Mid-Kansas Oil and Gas Co. drilled the deepest well of the year and of the pool. It is Lackey No. 6, in sec. 11, T. 5 N., R. 9 W. This well gaged 17,000,000 cu. ft. of gas from a Pennsylvanian sand at 4857 to 4971 feet, with a shut-in reservoir pressure of 1800 pounds.

Southern Oklahoma.—There were scattered activities in southern Oklahoma but no discoveries or extensions of especial economic importance. The Madill area of Marshall County was more active than usual with small completions in shallow pays thought by some to occur in the Hunton section. The Comanche field of Stephens County received several extension wells. The Tatums pool was probably the most active area of the territory. In this pool the Magnolia Petroleum Co. Dickerson No. 2, sec. 24, T. 1 S., R. 3 W., flowed 2465 bbl. initial from a series of sands at 1935 to 2131 ft. The Trevelyn Oil Co. Mitchell No. 1, sec. 24, T. 1 S., R. 3 W., made 2650 bbl. from a sand series at 2287 to 2447 feet.

The Natural-gas Situation

Natural gas in Oklahoma was first used as fuel for drilling wells as early as 1902. In 1904 it was distributed to domestic consumers in Tulsa, Red Fork, Bartlesville and Pawhuska. The earlier sources of field supply were located in northeastern and eastern localities of the state. For years the production of natural gas exceeded consumption, consequently large amounts were exported to adjoining states. Until recently, however, consumption increased more rapidly than production. The most significant development, however, is a recent reduction in price paid for natural gas at the well. A major purchaser and distributor has reduced the price at the well 40 per cent. This is the first state-wide price reduction in the history of the industry in Oklahoma. Whether this price reduction can be justified or not, it will have far-reaching effects. Already city commissions have joined the Corporation Commission of Oklahoma to make a study of natural-gas rates at city gates in an attempt to lower rates.

Oklahoma Panhandle.—This territory at one time was considered promising prospective oil land. The single oil showing in Cimarron County, considered significant by some in 1926, has so far not been followed by a single commercial oil well in the three counties comprising the territory. Eleven wells have been drilled to depths greater than 4000 ft. in Cimarron County, and five in Texas County. Operations, however, have resulted in the partial delineation of extensive natural-gas lands in parts of Texas County contiguous with the extensively developed natural-gas district of southwestern Kansas. There are six producing gas wells in Texas County with an open-flow volume of about 31,000,000 cu. ft., with pay depths ranging from 2650 to 2950 ft. Eventually about 160,000 acres should afford gas in Texas County, and at least 30,000 acres in the adjoining county—Beaver. Production is found in dolomitic limestones of Permian age, apparently the northern equivalents of the "Big Lime" section of the Amarillo district. Future developments may connect this district, by way of Sherman County, Texas, with the Amarillo gas fields of Texas.

Noble County.—Ten wells have been completed in the Waltermeyer pool in T. 21 N., R. 1 W., for an initial open-flow volume of about 160 million cubic feet daily at a depth of about 3400 feet.

Cement Field.—Previous developments in the Cement field afforded gas and oil in a number of sands from 1415 to 2800 ft. The 2200-ft. sand has been the most prolific natural-gas objective of the field, but in 1930 deeper pays were discovered. Since the Cement and Chickasha fields appear to lie on the same line of folding these new discoveries are especially significant, and at least suggest further important reserves of natural gas in this district. At 3406 to 3420 ft., the Magnolia Petroleum Co. encountered 51,000,000 cu. ft. of gas at its Sanes No. 3, in sec. 35, T. 6 N., R. 10 W. At 4857 to 4971 ft. the Mid-Kansas Oil and Gas Co. completed a 17,000,000-ft. well. This well, Lackey No. 6, is in sec. 11, T. 5 N. R. 9 W.

Beckham County.—The Sayre pool was discovered in 1922 with a gas well at 2747 to 2810 ft. that later showed oil. The pool covers about 6700 acres, less than half of which is developed. Production occurs in the "Big Lime" section, but about 200 ft. lower stratigraphically than the gas pays in the same group of the Amarillo fields. About seven billion cubic feet of gas have been withdrawn from the reservoir, probably not more than one-eighth of the ultimate recovery when fully developed and depleted.

Oklahoma City.—The Oklahoma City field is not only a spectacular oil field, it is also an important gas field, even though the supplies may not be properly and fully conserved. There are five natural-gas zones in the Pennsylvanian system that afford gas, but have not been explored in the rush for oil in the deeper objectives. The Simpson and Wilcox

sands and the Arbuckle lime of Ordovician age contain large volumes of gas as well as oil. Oil wells frequently afford as much as 150 million cubic feet of gas in these lower objectives. A completion in late November, the Blackwell Oil and Gas Co. Scruggs No. 1, in sec. 35, T. 12 N., R. 3 W., was gaged for 225 million cubic feet initial from the Wilcox sand at 6398 ft. There are 24 deep gas wells in the field, of which the Corporation Commission has classified 19 as strictly gas wells. Average reservoir pressures have declined fully 50 per cent. in the deeper zone. June 20 the Cities Service Co. completed 51 miles of 20 and 24-in. gas line from near Perry to the Oklahoma City field. This line has a capacity of 100 million cubic feet of gas daily and connects with its long-distance transmission system.

Pittsburg County.—There were additional gas-well completions in the Quinton field. One completion in sec. 5, T. 7 N., R. 18 E., gaged 22,000,000 cu. ft. of gas from a sand at 1823 to 1897 ft. Sufficient reserves were developed to warrant construction of 112 miles of 16-in. line from the field to Tulsa and intervening markets.

DISCUSSION

D. R. Snow,* Tulsa, Okla. The South Earlsboro field, which was mentioned as one of the more active areas, marks a new trend in Oklahoma development, in that it is the first field in Oklahoma to be recognized as a discovery by geophysical methods—the seismograph.

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Petroleum Developments in Texas during 1930, Except the Gulf Coast and Panhandle Districts

By M. G. Cheney,* Coleman, Texas

(New York Meeting, February, 1931)

The purpose of this paper is to review the more important developments in the production of petroleum during 1930 in Texas, excluding the Panhandle and Gulf Coast districts, giving emphasis to trends rather than to statistics.

Outstanding Developments

Aside from increasing curtailment of drilling operations and general prorating of production by state authority the most noteworthy developments for the year appear to have been:

1. Demonstrations of the fictitiousness of potentials as shown first by Darst Creek pool, rated at 180,000 bbl. and having actually 78,000 bbl. daily, and especially by the Hendricks pool of Winkler County, with potential of about 1,000,000 bbl. daily in mid-year and production of only 52,000 bbl. daily when opened to continuous full production in December.
2. Rapid development of the Darst Creek pool under competitive drilling.
3. Orderly and highly successful development of the Van pool under unit operation.
4. Failure of several highly rated structures southwest and northeast of Van.
5. Extension of the deep Simpson production at Big Lake and increased interest in these pre-Mississippian pays in North Central Texas and West Texas.
6. Discovery of prolific wells in northwest Rusk County from sands of Upper Cretaceous age, portending a rapid and extensive development campaign around the northwest margin of the Sabine uplift.

North Central Texas

It appears logical to discuss the new developments by districts as set out by the American Petroleum Institute, but North Texas and West Central Texas districts will be treated together.

Pre-Mississippian.—The pre-Mississippian beds, which in previous years yielded a few large wells in Young, Cooke and Callahan counties,

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failed to furnish any important new production in the 20 tests which were carried into these formations during 1930. Much more careful study is being given to these earlier Paleozoics which have proved so prolific in Oklahoma to the north and Big Lake field to the southwest.

Developments to date favor the expectation of small pools resembling in size and output the "Siliceous lime" pools of northeast Oklahoma and southeast Kansas but it is much too early to draw final conclusions as to potentialities of these older beds in this region with its 27,000 square mile area and its relatively unknown pre-Mississippian geologic history.

Bend.—The Bend (early Pennsylvanian) group furnished new gas wells in northwest Eastland, Stephens, Palo Pinto, Erath, Brown and Coleman counties and new oil production chiefly in Young, Stephens, Eastland and Jack counties.

Nash & Windfohr's No. 1 Hinson, 1 mile northeast of Graham in Young County, came in during May, 1930, at a depth of 3800 ft. for 24,000 bbl. of oil daily, the largest well on record for North Central Texas. Most of the 15 wells drilled near it were unproductive, which seemed to prove a fracture zone or fissure reservoir condition in the Smithwick (upper Bend) lime pay horizon. Irregularity of oil production and persistency of gas production are well-known characteristics of most Bend pays. Recent years have seen a gradual shift of attention in West Central Texas from the Bend to the overlying Strawn, Canyon and Cisco pay horizons. Production in the three last-named groups is mostly developed from true sands, accumulation being controlled in some cases by sand development rather than by structural conditions.

Strawn.—Various sands of the Strawn group furnished discoveries or extensions in Young, Jack, Brown, Coleman, Cooke and Denton Counties. Young County easily led the district during 1930, in new Strawn as well as Bend and Cisco developments, the first six months showing total initial production of almost 50,000 bbl. from 210 wells.

New Strawn developments include pools discovered about 12 miles west and 6 miles east of Graham and intensive development north from the Sinclair Moren well in southeast Young County. This discovery well is now 7½ years old, has produced over 1,250,000 bbl. and is still flowing 225 bbl. daily. This record indicates that an isolated well under choke and by slow recovery can produce as much oil as normally comes from 160 acres under usual close spacing and rapid extraction methods.

The Strawn sand developments in Brown County were near the Fry pool, which still holds the record as being the best Strawn pool ever developed in West Central Texas, having some 300 producing wells and an ultimate recovery now estimated at 9000 bbl. per acre.

Canyon.—New developments from sands of the Canyon group were noteworthy in Coleman, Brown, Montague and Cooke counties. The most important discovery seems to be a new pool from Cross Cut sand

at 1580 ft. at Burkett, in northeast Coleman County. Initial productions of from 200 to 560 bbl. were reported in the eight wells completed from September 1 to December 31. Although within 2 miles of two major purchaser pipe lines, no outlet could be secured. Most pipe lines of North Central Texas adopted the policy about mid-year of refusing new connections, including new discoveries of their own producing companies. While this policy helped to avoid unneeded new supply it tended to develop distress oil and undermine the market.

Cisco.—Noteworthy developments from Cisco sands occurred in Young, Wilbarger, Archer, Wichita, Shackelford, Baylor, Callahan, Jones, Taylor, Clay and Throckmorton counties. North Young County became especially active under stimulation of the Riggs pool, discovered early in 1930 and located 3 miles north of Newcastle, where initial yields in excess of 1500 bbl. daily were recorded from sand encountered at a depth of 700 ft. This pool by midyear had developed a potential production based on 2-hr. gages of about 20,000 bbl., and at the close of the year showed 12,000 bbl. potential based on the last hour of a 24-hr. gage, all wells being tested on the same day. Several more of these productive sand lenses equivalent in age to Archer County pays have been located in North Young County, bringing the total potential to about 20,000 instead of about 5000 bbl. daily, as of past years. Proration is holding the output to about 7500 bbl. daily.

Résumé.—Declining activity and sharp reduction of production and prices were the outstanding petroleum developments of 1930 for North Central Texas.

Production for the district declined from 142,000 to 87,000 bbl. daily during the year, or 38 per cent. as against 20 per cent. for all of Texas, and 20 per cent. for the United States. In spite of this curtailment (more than 100 per cent. greater than the rest of Texas) North Texas producers are blamed by companies that purchase crude oil for price cuts in the Mid-Continent and for the enormous losses which accrued as a consequence to oil companies, both large and small, to royalty owners and in state and county tax returns. However, the producers of this district, insist that their activities were less significant than the developments at Hobbs and Darst Creek and that rearrangement of pipe line systems and lack of cooperation among purchasers of crude with a view to arranging an outlet for about 4000 bbl. daily production were the main causes of the year's catastrophe in the Mid-Continent oil industry.

Northeast Texas

Lower Cretaceous.—The first commercial production from the Trinity Division of Lower Cretaceous (Comanche) in Northeast Texas (including East Central Texas of trade report) was recorded in 1930. Showings of oil and gas from these beds in the Mexia district have been recorded in

previous years. The discovery referred to is in the Bethany district of northeast Panola County, where three gas wells having a capacity of as much as 40,000,000 cu. ft. have been completed at 4700 ft. from the Glen Rose (upper Trinity) formation.

Shallower gas reservoirs of the Bethany area, encountered chiefly at about 3000 ft., or 500 to 600 ft. below the top of the Comanche beds, were developed further during 1930.

Upper Cretaceous.—The fault line pools of East Central Texas were producing about 17,000 bbl. daily at the beginning and 13,000 at the close of 1930. Proration is not applied to these pools because large volumes of water are produced with the oil, a condition has already caused extensive abandonment of small wells.

The Van field, discovered in October, 1929, has been the outstanding development in Northeast Texas during 1930. Fortunately for the industry, and all concerned, this field has been developed under unit operation. During 1929, three wells were completed; 40 during the first half of 1930 and 142 during second half of 1930, of which 178 were productive. Ten rigs are kept drilling under the present development program. These wells, flowing through 2½-in. tubing and $^{11}/_{16}$-in. choke now show total potential of 375,000 bbl. and under state-wide proration are allowed to produce 27,500 bbl. daily. Two 10-in. pipe lines were completed to this field during 1930.

The productive area of Van is estimated at 3300 acres within the unitized area plus 800 acres owned by the same interests outside this area, all of which is under the same proration schedule and umpire. Poulsen[1] says that some wells penetrated more than 300 ft. of Woodbine sand, this being several times the thickness of pay in the fault-line pools of East Central Texas.

It is evident that the Van field could have brought added demoralization to the oil industry during 1930 if it had been developed under unrestrained conditions such as prevailed at Powell, where within six months 500 wells were completed and production reached a peak of 356,000 bbl. daily. Van has produced 8,500,000 bbl. in 15 months, whereas Powell produced 30,000,000 bbl. in 7 months.

Difficult years like 1930 emphasize the many advantages of unit operation. It is interesting to speculate as to how much lower the price of oil in this field would be and what the total loss to the producing companies, royalty owners, industry at large, and the state and county would have been had Van, with potentialities several times greater than Powell, been developed in the same competitive manner.

In contrast to Van several other highly rated structures of Northeast Texas as determined by geologic and geophysical researches have now

[1] F. E. Poulsen: Development in East Texas and Along the Balcones Fault Zone, 1929. *Trans.* A. I. M. E., Petr. Dev. & Tech. (1930) 494.

been tested without success, notably Kelsey, Athens, LaRue and Blackfoot. More than 60 wildcat failures were recorded, with the result that the possibilities in Northeast Texas of other producing structures of the large broad domal type like Van appear more and more improbable.

However, persistent wildcatting was rewarded near the end of the year by discoveries in northwest Rusk County along the east flank of the East Texas embayment. After losing two holes, C. M. Joiner on October 3 found pay sand at 3536 ft. in his third test, 1½ miles northwest of Joinerville. This well made only 250 bbl. daily but it started a very active play. Dry holes have proved that this well is near the east edge of a sand body which lies immediately below a comparatively thin chalk of Austin age. If the sand is of Austin age, as some geologists contend, it may be equivalent to some part of the Tokio sand of southwest Arkansas, but other geologists favor the interpretation that this is the east edge of the Woodbine sand.

The completion of wells 1 mile west and 9 miles north and (January, 1931) 25 miles north, which gage 400, 900 and 750 bbl. per hour respectively on 1 to 2-hr. gages show this trend to be one of great potentialities. The latter two wells are on fairly large lease blocks, but small leases prevail over much of the intervening area. Proration seems to be the only hope of preventing excessive production from this new producing area. The failure of the large Kelsey structure in western Upsher County, the usual lenticular nature of shore-line sand deposits, the thinness of pay in wells so far completed and the lack of active demand for new supplies of crude render difficult both the appraisal of this district and predictions as to how profitable and aggressive its development will be. At present this new area is the center of attention for the entire Mid-Continent region.

Southwest Texas

This district experienced a fairly well sustained activity during 1930, production averaging 57,500 bbl. at the beginning of the year and 77,500 daily at the close.

Pre-Comanche.—In the Edwards plateau area the pre-Mississippian beds received some attention during 1930 but no significant development was reported.

Pennsylvanian prospects of this large area, however, were brightened by the Evans-Gant et al. Love No. 1 in southwest Kerr County. This well found oil and gas in sands at 2544, 3341 and 3380 ft. The well started in January, 1931, producing over 100 bbl. of 40° gravity oil daily from this third sand. The second sand makes occasional flows between casing strings. It seems impossible at present to predict how active or successful further prospecting of this large Strawn (?) basin on

the southwest side of the Llano-Burnett will be, but this strike gives encouragement. Much of the area is held by the larger companies in large blocks of paid-up leases. Both the underlying Bend and to the west of Kerr County the overlying Canyon and Cisco equivalents doubtless hold some possibilities of production. Activity was moderately stimulated by this discovery well.

Comanche.—Upper Trinity (Glen Rose) beds yielded initial production totaling 24,000,000 cu. ft. of gas and 92 bbl. of high-gravity oil in three wells in the Chittim pool 12 miles northeast of Eagle Pass in Maverick County. Like the strike in Kerr County, these wells draw attention to the commercial possibilities in new large basin or embayment areas of geologic formations which have established their petroliferous qualities in other areas.

The major new development in these Lower Cretaceous beds during 1930 was limited to Darst Creek pool, about 10 miles southwest of the Luling pool. Discovered in July, 1929, this typical fault-line pool did not receive active development until 1930. Maximum potential of 245,864 bbl. was recorded in May from 128 wells, and although restricted by proration most of the year this pool produced about 11,000,000 bbl. The Luling pool has now produced over 52,000,000 bbl. Darst Creek may equal this figure. The oil is 36°, instead of 28° gravity oil as at Luling. Considerable wildcatting for other Edwards lime pools was carried on without success during 1930.

Upper Cretaceous.—A few crevice wells were developed from the Austin chalk in various pools, but the major development of this age was a new serpentine pool discovered by the Chapman Abbott No. 1 in January, 1930, located 8 miles south of the Old Thrall pool in Williamson County and about 30 miles northeast of the Yost, Lytton Springs and Dale pools, in all of which serpentine is the main reservoir rock. The year's production from the Chapman pool was more than 2,000,000 bbl., its 65 wells having an estimated potential several times its allowable production of 5400 bbl. daily at the close of the year. About 25 wildcat tests are seeking other serpentine pools in this district. Navarro and Taylor marl formations furnished a few new developments, apparently of minor importance.

Tertiary.—The Laredo district has had a fairly successful year, adding greatly to its large gas reserves and increasing its output from 9,000 to 14,400 bbl. daily during 1930. The 20° to 22° gravity oil of this district gained an enviable reputation at proration hearings as suffering no physical waste from evaporation and requiring a large conflagration to set it afire. The main activity of 1930 was along the trend from northeast Zapata to north-central Duval County, where numerous pools have been discovered at moderate depths, mainly from 1300 to 2300 ft., from various sands of Cook Mountain and Jackson age.

West Texas

The large Permian basin area of West Texas and Southeast New Mexico probably lost more potential than it gained in 1930, the largest gain being about 1,000,000 bbl. in the Hobbs pool in Lea County, New Mexico.

For the third consecutive year the total production in the Texas part of the basin was over 100,000,000 bbl. There was apparently no new discovery of prime importance. Production at the end of the year was about 237,000 against 340,000 bbl. daily at the beginning of the year. This decline is in part due to proration but many pools have had an allowance practically equal to their true potential, or as high as good production management would permit. Hendricks pool produced nearly 59,000,000 bbl. in 1928; 50,000,000 bbl. in 1929 and about 28,000,000 bbl. in 1930. As mentioned, its potential of 1,000,000 bbl. in the summer of 1930 was found to yield an actual of 52,000 bbl. daily when opened in December.

In the second major pool of West Texas, the Yates, more than 10 per cent. of the wells are showing water in amounts varying from 2 to 88 per cent., some being located near the center of the field. Encroachment of water under present restricted flow is being held in check successfully. Production from this open-pored reservoir cannot be safely increased to any great degree. The Yates pool produced nearly 40,000,000 bbl. during 1930, an increase of about 9,000,000 over 1929. However, the daily production of 137,700 bbl. at the beginning of the year had been reduced to 91,000 bbl. at the end of the year, the latter being an average of about 260 bbl. daily from each well.

West Texas had about 30 active wildcat tests at the close of the year. Several producing areas and trends promise much new production for the future but it now appears that West Texas may have established its all-time peak production in 1929, approximately 125,000,000 barrels.

Pre-Mississippian.—The deep pay of the Big Lake pool experienced successful development during 1930. The six new wells completed from 8500 to 8900 ft. deep brought production to about 13,000 bbl. of oil and 100,000,000 cu. ft. of gas per day. The discovery well brought in in November, 1928, still maintains a daily flow of 2800 bbl. and 20,000,000 cu. ft. of gas. An eighth well, completed the middle of January, 1931, has set the high record for the pool of 7000 bbl. and 60,000,000 cu. ft. of gas. These wells are now known to be producing from sharply folded limestones and sandstones equivalent in age to the Hunton and Simpson (including Wilcox sand) formations in Oklahoma. Six wildcat tests in as many counties are seeking this deep pay. The areal extent of these beds is a matter of conjecture. There is some evidence that they will be absent over the Yates-Hendricks-Hobbs trend ("central basin platform") and the area northwest from the Llano-Burnett uplift ("Concho divide").

Mississippian and Pennsylvanian.—No Mississippian or new Pennsylvanian producing areas were found in West Texas during 1930. The recent Love well in Kerr County (see Southwest Texas) gives some encouragement for continued prospecting, particularly on the northeast flank of the deep geosyncline extending from the Marathon district east and southeast beneath the south part of the Edwards plateau. A flexure no doubt developed around the margin of this basin resembling the Bend flexure of North Central Texas, but westward tilting has tended to obscure this feature in West Texas instead of emphasizing it as in the other area.

Permian.—The Cranfill Bros.-Gulf Production Co. No. 1 Tubbs, in west-central Crane County, created much stir about midyear by developing a large flow of oil and gas at 4300 ft. in the lower part of the "Big Lime" and below sulfur water horizons, which had theretofore been considered the end of prospects for oil in the Permian. However, the well has decreased to 25 bbl. of oil and 2,000,000 cu. ft. of gas daily. Drilling has now continued to about 4600 feet.

The usual pay near the top of the Permian "Big Lime" was responsible for new production of note in several localities, especially in the Penn-Kloh area in southeast Ector County, and a new 250-bbl. wildcat discovery in the northeast part of Ector County. The former reached a potential of about 20,000 bbl. and had a daily production of 7000 bbl. from about 75 wells at the end of 1930.

The sands occurring about 300 ft. above the "Big Lime" in the Shipley area of Ward County received slight attention in this year of retrenchment.

Trinity.—Some 38 wells were completed 9 miles northwest of the Yates pool, at a depth of about 300 ft. Trinity sand and gravel served as the reservoir in this pool. Initial yields were as high as 200 bbl. daily but total production from the pool did not exceed 1000 bbl. per day. The oil is 25° gravity.

Note

The attention of the reader is called to helpful maps and rather detailed reports for 1929 of the districts discussed herein, as published in the 1930 A. I. M. E. *Transactions*, Petroleum Development and Technology (pp. 476–509), written by R. E. Rettger, F. E. Poulsen, J. Whitney Lewis and Olin G. Bell.

Petroleum Developments in Texas Panhandle in 1930

By W. E. Hubbard* and H. E. Crum†

(New York Meeting, February, 1931)

This review covers the northern 32 counties of the Texas Panhandle, an area 180 miles square. The westerly three-fourths of the district lies wholly within that great area known as the Llano Estacado or "staked plains." Six of the counties produce oil and gas and three produce gas alone. All of the production is associated with the Amarillo arch, a huge anticline superimposed upon a buried mountain range which is undoubtedly a continuation of the Wichitas of southwestern Oklahoma.

Oil Production

The production of the Texas Panhandle up to Jan. 1, 1930, was slightly over 157 million barrels, 90 per cent. of which came from Hutchinson and Gray counties. About 33,000,000 bbl. was produced during 1930. Though this was about 9 per cent. above the 1929 production, it was over 8,000,000 bbl. less than was produced during the peak year, 1928.

The present daily production is slightly over 40,000 bbl., which is the allowable production under state-wide proration. The assumed potential for the purpose of proration is 124,500 bbl. and the actual capacity of the wells probably would be in the neighborhood of 100,000 barrels.

The total initial production of the oil wells completed in 1930 was 157,289 bbl. from 308 wells, or 511 bbl. per well, as compared to a 734-bbl. average from the 350 oil wells drilled during the preceding year. The completions in Gray County numbered 232, with an average initial of 614 barrels.

Completions

During 1930, 526 wells were completed in the Panhandle as compared to a total of 503 during 1929. Of the year's completions, 308 were oil wells, 169 produced gas and 49 were dry holes. Of the 3027 wells drilled in the Panhandle to date, 2780 have produced oil, gas or both, making the ratio of dry holes to producers about 1:11.3. Ignoring the 63 dry holes drilled in nonproductive counties, the ratio becomes 184:2780 or 1:15.1 which is slightly less favorable than that which obtained at the end of 1929.

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Of the oil wells completed, 241 have been plugged. Almost 80 per cent. of the oil wells plugged have been in Hutchinson County, where the coning of bottom water has been rapid, probably owing to shooting with excessive shots and failure to conserve the gas occurring with the oil by the proper application of back-pressure.

Gas Wells

There were 168 gas wells completed in 1930, with a total open-flow capacity of 4,139,000,000 ft., or an average of 24,640,000 ft. per well, as compared with 111 wells averaging 26,400,000 ft. in 1929. Table 1 shows the total number and capacity of completed gas wells by counties.

Table 1.—*Completed Gas Wells in Panhandle*

County	Number of Gas Wells	Total Capacity, Million Cu. Ft.	Avg. Volume per Well (×1,000,000)
Carson	102	2,869	29.1
Collingsworth	2	4	2.0
Gray	85	1,869	22.0
Hartley	5	101	20.2
Hutchinson	72	2,077	28.8
Moore	34	852	25.0
Potter	35	716	20.5
Wheeler	198	5,905	29.9
Total	533	14,394	27.0

To be added to these are 62 oil wells plugged back for gas during the past four years, which probably have a combined open-flow capacity of about one billion feet daily.

A little over 40 per cent. of the gas wells completed in 1929 were drilled in Wheeler County.

It is estimated that 440 billion feet of gas were taken from the Amarillo arch during the year, bringing the total withdrawal to date up to 1½ trillion feet. Even this staggering total is probably not over 14 per cent. of the total recoverable gas originally contained in the million-odd acres of known gas territory in the Panhandle.

Based upon the average daily consumption per meter in Dallas, Texas, one-third of the open-flow capacity of the 532 completed gas wells would be sufficient to take care of the domestic needs of 120 million people.

The increasing interest in proration in Texas has forced the attention of Panhandle operators more and more toward the conservation of pressures in the oil-gas horizon. Inasmuch as the dry gas and the oil-gas horizons are connected, a common problem exists, and it will be to the

benefit of every producer to use all reasonable means to prevent the wastage of gas.

Casinghead Gasoline

The total number of plants increased during the year from 52 to 53. Two new plants were built in Gray County and one was abandoned in Hutchinson County. Plants in operation are shown in Table 2. The total casinghead gasoline production for 1930 was 304 million gallons, or 50 per cent. more than that of the preceding year. The yield per barrel of oil produced was correspondingly greater, being 9.1 gal. per barrel in 1930 and 6.5 gal. per barrel in 1929.

Table 2.—*Casinghead Plants as of January* 1, 1931

County	Number of Plants	Capacity, Cu. Ft.
Carson	10	126,045,000
Gray	18	368,000,000
Hutchinson	17	378,000,000
Wheeler	3	25,000,000
Moore	1	2,225,000
Total	49	899,920,000
Domestic Gas Line Plants (Gas from Gas Wells)		
Moore	1	60,000,000
Potter	2	32,500,000
Wheeler	1	40,000,000
Total	4	132,500,000

Carbon Black

The Texas Panhandle contains 24 plants manufacturing carbon black —over one-third of the total number in the United States. These plants manufacture about 54 per cent. of the total carbon black produced in the world. During 1930 the average daily production for the Panhandle was about 600,000 lb. from slightly over 400 million feet of gas, or a yearly production of around 110,000 tons from 120 billion feet of gas. All of the gas is processed for gasoline before burning in these plants.

As of the last of the year there were approximately 79,000 tons of carbon stored in the Panhandle, which is about 20 per cent. in excess of the total stocks held by all producers in the United States on Dec. 31, 1929.

Proration Program

Proration measures were in effect in the Panhandle during the first quarter and the last four months of the year. During the first part of the year curtailment was confined to the prolific Bowers and Finley pool areas of Gray County, the percentage of cut varying from 20 to 35 per cent. of the potential. In the latter part of March an effort was made to extend the existing proration so as to cover all of Carson, Gray and Hutchinson counties, with provisions for exempting each 80-acre unit having a production of 100 bbl. or less. Considerable opposition developed and the plan was abandoned. Such curtailment as still existed was also discontinued and it was not until state-wide proration began, at the end of August, that a further attempt was made to cut back production. Despite some violations, the production was held at approximately 80,000 bbl. for the months of September, October and November, a curtailment of some 30 per cent. Owing to the existence of many unconnected leases and wells, the allowable production was cut to 40,000 bbl. on December 16, in order that all properties might share equally in the nominations of the various purchasers.

Drilling and Production Practice

Fair progress in drilling and production practice was made during the year. The use of the acid bottle became general and as far as known no holes of prohibitive deviation were drilled. The use of heavier rotary equipment, especially boilers and pumps, helped to cut the average time from spudding to completion from about 60 days in 1929 to a little over 40 days in 1930.

Apparently more care was taken in coring for the oil horizon, and a core barrel was developed suitable for the interbedded hard and soft series of the granite wash pay horizon. Another development that has considerable promise is a type of "jars" used on the oil string in conjunction with a flexible connection and an oil-saver control-head at the surface whereby the lifting of the pipe on the elevators causes variable ports opposite the gas horizon above the oil pay to open progressively and allow the proper amount of gas to enter to lift the oil and maintain a suitable gas-oil ratio. Smaller flow strings and elevated traps set close to the wells were in more general use.

Modern rig fronts and pumping units were used in many instances and central pumping powers for wells 3000 ft. deep gained a small foothold with apparent success. During the latter part of the year cupless plunger-type working barrels for both shallow and deep pumping gained some favor. Although several new chemicals were tried out with varying success, no universal remedy for paraffin troubles was discovered and heat in the form of hot water and steam still remains the method in general use.

New Developments in 1930

Hartley County.—In the southeastern part of the county, Dana Oil & Gas Co. extended the known gas area about 4 miles to the north but its low structural position would indicate that production will not extend much farther in this direction.

Potter County.—A number of gas wells were drilled in the proven area of the northern part of the county. Close to the Potter County fault, the Prairie Oil & Gas Co. drilled its Bivins No. 13A, which found free oil in the dolomite section of the Big Lime.

It is possible that oil in commercial quantities will be found in this area. The well showed that the formerly supposed displacement of over 1200 ft. in the Potter County fault is not to exceed 900 feet.

Moore County.—In April, the Sunray Oil Co. and others completed a semiwildcat 3 miles northeast of the Morton well in northeastern Moore County, which at first appeared to have opened an important new oil pool. The well was drilled into water, however, and was completed for 200 bbl. Offsets and near-by wells have been disappointingly small and have demonstrated the highly erratic character of the oil-producing zone of the gray lime division of the Panhandle Big Lime. The widespread distribution of oil in this horizon was shown by the completion by the Shamrock Oil & Gas Co. of a 600-bbl. well 4 miles southwest of the Morton well. Gas development has been active during the year in the proven gas areas in the southern part of the county. In the extreme western part of the county, Dana Oil & Gas Co. Anthony No. 1 was completed as a dry hole and demonstrated the existence of a structurally low area in this direction.

Hutchinson County.—Six wells were drilled between the Dial, Merchant and Armstrong pools but failed to find commercial oil production; four were completed for small gas wells and the others were abandoned. About 20 wells were drilled in the southwestern part of the county, which resulted in the extension of the Pantex pool, and a number of other commercial producers were found in granite wash similar to the Pantex pool. All of the wells found gas in large volumes and those which failed to find commercial oil were completed as gas wells. The rock pressure in this area averages about 350 lb. In the southeastern part of the county the Moore-Cooper pool was extended to the northwest, the production coming from the brown dolomite division of the Big Lime. There was practically no new development in the old Borger, Dial and Sanford pools and many wells were plugged and abandoned during the year.

Carson County.—Empire Gas & Fuel Co. completed Field No. 1 in March for an initial production of 1900 bbl. The well is in east central Carson County and is on the south side of the main Panhandle fold. It appeared to have opened an important new area of production from the granite wash. Six additional wells have been drilled in an attempt to

extend the field, only one of which succeeded in obtaining oil in commercial quantities. The development has defined a condition of steep dip or of possible faulting. In the southeastern part of the county Rieger et al. found free oil in the dolomite section just above the granite wash. Although not of commercial proportions, this discovery may be the forerunner of oil production in this area, which is also on the south side of the main fold. On the 6666 dome in the northern part of the county a large number of gas wells were drilled to supply the trunk lines. A few wells were drilled in the proven oil trends of the northeastern part of the county. Initial production along these defined trends is consistently at an average of 250 bbl. per day.

Gray County.—The Finley pool was extended to the north and to the east, the wells averaging 1500 bbl. initially. The Bowers pool was extended somewhat to the southeast and to the north a deepening of a number of wells demonstrating lower pays in the granite wash. A number of producing wells were completed in the LeFors, Saunders and Morse pools. The most active development occurred in the West Pampa pool in the northwestern part of the county. This area has been known for several years but has not been intensively drilled until this year. Production comes from the dolomite section of the Big Lime and the wells have an average initial production of 250 bbl. This production is noted for its long life.

The feature development was the semiwildcat well of the Taconian Oil Co. near the Santa Fe R. R. east of Kingsmill. A number of small wells had been found in the granite wash in this area and nothing of importance was expected from this test. After penetrating 90 ft. of hard and sharp granite wash section, the well entered a fractured zone or crevice and flowed out of control for several days. The initial production was 12,000 bbl. per day and showed no indications of its declining in production from the time of its completion in September until late in December, when water appeared in the well. Subsequent development in the immediate vicinity has found only one commercial well, the others to date having failed to find conditions similar to the discovery well. Wells such as the Taconian may be expected in the Panhandle district wherever faulting is indicated.

Wildcats in the southern and southwestern parts of the county have resulted in failures. Completion of Brady et al. Talley No. 1 in the northeastern part of the county defines the low structural position of this area.

Wheeler County.—Development of the proven gas area was active during the year; the Lela district was extended to the west and south with volumes averaging 30,000,000 cu. ft. and rock pressures averaging 400 lb. Woodley et al., in the extreme southeastern part of the county, drilled what appears to be a commercial oil well 15 miles from the nearest

production. This area has been known to lie at a favorable structural datum and the finding of oil was not unexpected.

Other Counties.—Shoup et al. drilled a wildcat in northern Collingsworth County with several shows of oil and gas but the test was abandoned after penetrating 1200 ft. of granite wash. Aside from this test, exploratory activities in other than the producing counties have been practically at a standstill.

Oil Developments to Date

To date, about 30 separate oil pools have been opened in the Panhandle. In size they vary all the way from those containing one well to pools covering thousands of acres. It is probable that the 2200 oil wells drilled to date will have an ultimate production of somewhat over 200 million barrels, which would indicate an average yield per acre of about 9500 barrels. Table 3 shows the pertinent data with respect to the separate pools.

Outlook for Production

Little has occurred during 1930 to change the outlook for future production. At such a time as development is warranted, the known pools and defined trends of production will be extended with full confidence of finding commercial production. Attempts to find new pools will not be promoted in the near future although buying of scattered acreage and some blocking of acreage during 1930 would indicate that a number of localities throughout the 150 miles of proven and semiproven territory is regarded with favor by the operators.

As far as the known producing horizons are concerned, it may be stated that the prospective oil territory along the Amarillo arch is from 20 to 30 per cent. developed. Should future wells be as productive as the average well drilled in the past the total production from the Lower Permian and the Upper Pennsylvanian in the present oil-producing counties should be between 750 and 900 million barrels. Many well informed oil men probably will not admit the possibility of such a generous estimate but as most of the forecasts made in the past, covering large area, have been far too low the writers think that the total figure will be close to 900 million barrels.

Prospective Deeper Horizons

The deepest production in the Panhandle is obtained from the granite wash and gray lime formations of Pennsylvanian age. On the higher parts of the Amarillo arch these formations are known to rest upon granite, thus eliminating the possibility of obtaining oil below them.

TABLE 3.—*Oil Development in Texas Panhandle to January* 1, 1931

Field	Location	County	Discovered	Completed Oil Wells 1-1-1931	Average Depth, Ft.	Production to 1-1-31	Daily Prod.,[a] 1-1-31	Gravity	Producing Zone[b]	Age[c]
Burnett	Blk. 5, I. & G. N. 4 mi. south of Borger	Carson	5- 2-21	55	3,050	3,790,000	235	36–40	G. W.	U. P.
Cooper-Moore	Around sec. 111, blk. 4	Carson-Hutchinson	10-25-27	74	3,200	2,032,000	1,660	38–40	Dol.	L. P.
Fields	NW. part blk. 7, I. & G. N.	Carson	2-15-30	2	3,250	86,000	49	43.5	G. W.	U. P.
Noel	Secs. 66 & 67, blk. 4; secs. 187, 188, 198, 199, blk. 3	Carson	1-13-27	60	3,200	3,411,000	798	43.0	G. W., Li.	U. P.
Republic	NW. part blk. 4	Carson	10-21-26	5	3,200	220,000	37	36–39	G. W., Li.	U. P.
Roxana	Around sec. 92–107, blk. 4	Carson	9-22-26	64	3,100	4,704,000	902	38–44	G. W., Li.	U. P.
Back	Sec. 44, blk. 25	Gray	5-25-27	9	2,600	150,000	150	42–44	G. W., Li.	U. P.
Bowers	Around sec. 89, blk. B2	Gray	7-24-25	122	3,000	18,153,000	6,724	42–44	G. W.	U. P.
Chapman	Around sec. 51, blk. 25	Gray	12-15-26	27	2,850	1,800,000	440	42–44	G. W.	U. P.
Finley	1 to 3 mi. west of Lefors	Gray	3-25-29	154	2,850	14,235,000	9,397	38–41	G. W.	U. P.
Kingsmill (W. Pampa)	1 to 4 mi. west of Pampa, blk. 3	Gray	4- 8-26	98	3,300	1,714,000	4,973	44–46	Dol.	L. P.
LeFors	N. part blk. 1 A. C. H. & B.	Gray	5-25-27	102	2,800	5,268,000	2,393	38–41	G. W.	U. P.
McConnell	Around sec. 174, blk. 3	Gray	11-26-27	25	3,250	862,000	364	44–46	G. W., Li.	U. P.
Morse	Secs. 1–5, blk. 26	Gray	7-19-27	38	2,550	908,000	1,595	43–44	G. W., Dol.	U. P., L. P.
Pampa	Around sec. 83, blk. 3	Gray	7-25-25	157	3,200	8,946,000	957	41–43	G. W., Li.	U. P.
Saunders	Around sec. 40, blk. 3	Gray	5-18-27	22	3,100	1,402,000	803	41–44	G. W., Li., Dol.	U. P., L. P.
Sullivan	3 mi. southwest of Pampa	Gray	9-14-30	3	3,100	406,000	3,600	41–44	G. W.	U. P.
Borger	Blks. Y, B4, 46	Hutchinson	3-22-24	883	2,900	69,985,000	3,920	34–36	Dol., Li.	U. P., L. P.
Cockrell	Blks. B3, 23	Hutchinson	4-21-27	40	2,900	3,679,000	618	34–36	Dol., Li.	U. P., L. P.
Dial Ranch	Around sec. 1, blk. X02 N. of Canadian River	Hutchinson	9-10-23	142	2,950	8,753,000	1,005	38–40	Dol.	L. P.
Merchant	Secs. 36, 37, 38, blk. 47	Hutchinson	1- 5-27	8	2,750	594,000	97	38–40	Li.	U. P.
Pantex	Around SW. cor. sec. 35, blk. Y	Hutchinson	1-28-27	9	3,150	1,451,000	716	38	G. W.	U. P.
Sanford	Secs. 81–86, blk. 46	Hutchinson	5-15-29	36	2,950	2,072,000	336	38–40	Li.	U. P.
(Armstrong)	11 mi. N. of SE. cor. of county	Moore	8-25-27	18	3,200	951,000	220	32–38	Li.	U. P.
(Morton)	Secs. 164–191, blk. 3T	Moore	6-24-27	5	3,400	20,000	170	37	Li.	U. P.
Warwick	NE. cor. county, sec. 16, blk. Y2	Potter	6-12-26	1	3,050	36,000	12	38–40	G. W.	U. P.
Bentley	Blks. 24 & 27, H. & G. N.	Wheeler	2-10-25	42	2,300	1,684,000	223	36	G. W., Dol.	U. P., L. P.
Total				2,201		157,294,000	42,393			

[a] Allowable production under proration (70 per cent. curtailment).
[b] G. W. = granite wash; Dol. = dolomite; Li. = lime.
[c] U. P. = Upper Pennsylvanian; L. P. = Lower Permian.

It is possible that Ordovician and other prospective formations that are known to exist in the Wichita Mountains of Oklahoma may extend to the northwest and be present along the lower flanks of the arch, especially in the Anadarko Basin, which lies on the north side of the Amarillo fold. If such a condition exists, favorable structures which may be found by drilling in the Anadarko Basin constitute a possible future prospect for oil in the district. From present structural knowledge, however, such horizons would lie at considerable depths and prospecting for them is not expected in the near future.

Petroleum Developments on the Gulf Coast of Texas and Louisiana during 1930

By L. P. Teas,* Houston, Texas

(New York Meeting, February, 1931)

Although 1930 has been a year of stagnation, proration and curtailment, the Gulf Coast has measured up to its tradition in the matter of interesting and significant discoveries. Only 2 domes and 7 new structural areas were brought into the producing column in 1930, whereas, in 1929, 13 domes and one structure were added to this list, yet a total of 14 new producing horizons were proved on various domes and structures. On 5 domes new flanks were successfully tested for commercial production. The year 1930 has shown at Barber's Hill that oil in commercial quantities may exist below salt or cap. Numerous wells have been drilled through cap, or even salt itself, into good producing sands. The past year has been particularly notable in the interest and in the number of deep holes drilled. Two wells have gone below 8000 ft. in each of the states of Texas and Louisiana, and in the two states together 14 wells have gone below 7000 ft. At the beginning of the year only one well was producing below 6000 ft. in coastal Texas, while at its end, 19 wells were producing or had produced. Geophysical discoveries and activity on the Coast have waned and this type of work has moved further inland.

The peaks of production at Pettus, Barber's Hill, Raccoon Bend, Refugio, Orchard and at Humble, in Texas; and at Lake Barre, Port Barre, Black Bayou, White Castle and Vinton in Louisiana, were seen this year. These were new peaks for Humble and Vinton, of course, these fields having previously gone through periods of peak flank production.

In Table 1 the completions listed are for the entire month of December in both years. It is remarkable that in 1930, a year of overproduction and proration, there were actually more wildcat operations at its end than at the end of 1929; but it is gratifying that the operations in the proven fields were exactly one-half what they had been at the end of 1929.

The price of A grade coastal crude, or oil below 25° Bé., has been cut from \$1.30 at the beginning of the year to \$1.00 at its close; and B grade, or oil above 25° Bé., has been reduced from a price range of \$1.15 to \$1.63 down to a range of from \$0.75 to \$1.22. In spite of these reductions there has been no proration program on the Coast. Systematic

* Humble Oil & Refining Co.

proration has continued in force, however, at Sugarland, Raccoon Bend and Pettus only.

At the beginning of the year the Gulf Coast was producing 178,200 bbl. daily, of which 157,500 was from Texas and 20,700 bbl. from Louisiana; while at the end of the year there was a total daily yield of approximately 192,000 bbl.; 164,000 bbl. from Texas and 28,000 from Louisiana.

TABLE 1.—*Comparative Operations on Gulf Coast at End of* 1929 *and* 1930

	Proven Fields		Wildcat Areas	
	End of 1929	End of 1930	End of 1929	End of 1930
Locations	27	3	2	1
Derricks	23	4	4	4
Rigs	10	5	0	2
Drilling	135	83	30	52
Shut down	6	13	25	32
Completions	83	34	15	13
Total operations	284	142	76	104

TABLE 2.—*Daily Coastal Production at End of* 1930 *by Depths*

	Above 2,000 Ft.	2,000 to 3,000 Ft.	3,000 to 4,000 Ft.	4,000 to 5,000 Ft.	Below 5,000 Ft.	Below 6,000 Ft.	Total
Texas	9,000	12,700	80,600	21,900	34,300	3,700	164,000
Louisiana	300	3,800	12,400	4,000	3,500	4,000	28,000
Totals	9,300	16,500	93,000	25,900	45,800	7,700	198,200

GEOPHYSICAL DEVELOPMENTS

Although the large amount of geophysical work done on the Gulf Coast in 1930 apparently has accomplished little, it cannot for that reason be condemned. The year has seen the completion of the first phase of the application of geophysics to the discovery of petroleum on the Coast. Practically all of the shallow domes have been found and the goal set by geologists for geophysics has been attained and even exceeded. We have entered the second phase of geophysics, or its application to the discovery of deep domes or structures in which the data are much less definite than those of the first phase, and hence capable of a much wider range of interpretation, and in which the results are being attained much more slowly and the proofs of the findings are much more difficult than in the first period.

In 1930 no definite domes or structures have been found, although a number of minor seismic and gravity anomalies have been noted. How-

TABLE 3.—*Coastal Salt Dome Discoveries to* 1931

	Producing		Nonproducing		
	By Geology or Other Means	By Geophysics	By Geology or Other Means	By Geophysics	Total
Texas	22	10	11	13	56
Louisiana	12	14	6	22	54
Totals	34	24	17	35	110

ever, these do not deserve a high rating until they have been proved by deep wells. Commercial production has been attained on two geophysical domes—Moss Bluff and Mykawa. On three other geophysical prospects—Danbury, in Brazoria County, and at Sheppard's Mound and Citrus Grove in Matagorda County—oil or gas in amounts significant enough to make them interesting has been found. Some idea of the great reduction in geophysical work may be had from the fact that at the beginning of the year 83 torsion balances and 25 seismograph crews were at work on the Coast and that at the end of the year there were only 65 torsion balances and 12 seismograph crews in active operation. During the past four months particularly there has been a great reduction in geophysical work.

Due to the scarcity of new discoveries in the salt-dome area on the Coast proper, the tendency has been to withdraw from it and prospect further inland or along the southern sector of the Coast where few domes are as yet known. There has been considerable experimental reflection work in progress during the past year. Some of the crews that had been operating on the Coast in 1929 have been moved to East Texas or West Texas.

In Texas the Danbury dome has been added to the list of proven geophysical domes through the discovery of salt in the Shell's Blakely-Winston No. 1 at 5221 ft. In Louisiana, Vermilion Bay, Choctaw, Lake Washington and probably Venice have been added to the proven list of geophysical domes. The Vacuum, at Cameron Meadows, in Cameron Parish, has had important gas showings but as yet has not proved a dome.

The year has seen much money spent in deep drilling, particularly in Louisiana, in unsuccessful efforts to prove geophysical prospects. In Texas the Rycade's prospect northwest of Moss Bluff in Liberty County; the Pure's two prospects, one in Chambers County southwest of Lost Lake and the other in Jefferson County west of High Island; the Rycade's on Austin Bayou in south central Brazoria County; the Humble's at Devers, in Liberty County southwest of Hull; Cockburn's at Deer Park in Harris County; Sloan's at Cedar Bayou in Harris County west of Barber's Hill; and the Gulf's at Clodine in Fort Bend County, have all been drilled without apparent success.

In Louisiana, the following companies have failed to prove geophysical prospects by deep drilling: the Humble at Barataria, in La Fourche Parish; the Vacuum at Paterson; the Pure Oil Co. at Wax Lake in St. Mary's Parish, and the Texas Co. at Leesville in La Fourche Parish.

New Fields

Moss Bluff.—On January 3, Humble Oil & Refining Co. Sterling No. 6 was brought in for 800 bbl. on a ⅝-in. choke from a depth of 5666 ft. The oil is 26.4° Bé. There had been four other previous flank tests here, which were unsuccessful. The production is from sand about 200 ft. below the Heterostegina lime of Middle Oligocene age, probably the same horizon as the 5000-ft. zone at Barber's Hill. Moss Bluff is a shallow dome (cap 600 ft.) that was found in 1926 with the seismograph, by the Gulf Company.

Mykawa—On September 27 the Humble Oil & Refining Co. Minnetex No. 3, the seventh well to be drilled at Mykawa, 12 miles south of Houston, was finished at 4873 ft. for 558 bbl. of 27.6° Bé. oil. This production comes from the upper part of the Frio formation of Oligocene age, about 500 ft. below the top of the Middle Oligocene. At Mykawa the Humble had previously, in Irwin No. 2 at 4189 ft. and later in Siadous No. 1 at 4933 ft., attempted unsuccessfully to establish permanent oil and gas production. The uplift here is about 900 ft. and the structure was found by H. C. Cockburn with the torsion balance in 1928. Salt, if present, is apparently very deep, since a well within the area of the uplift failed to find it at 6672 ft.

Pettus.—During the past four months of 1930 the entire Pettus production has been held steady at about 8500 bbl. The Houston Oil Co. McKinney No. 1, although brought in in December, 1929, was not produced until February. Development was slow at first but quickened in July, when the first town-site well was finished. The potential for the field at the close of the year was approximately 19,000 bbl. This was due to the rapid town-lot development, where 18 wells are now producing, although the initial well here, T. B. Slick, block 37, came in during July. The potential yield of these 18 wells decreased during November from 12,374 to 7,678 bbl., which clearly indicates the bad effects of overdrilling.

Other significant developments in the general Pettus area were the discovery of the Cosden pool, 6500 ft. west of the Pettus town site, by the Cosden Oil Co. McKinney No. 1, at 3676 ft. for 425 bbl. of 45.8° Bé. in the Pettus or McKinney sand during June. Since then seven wells have been finished and the pool is making 1000 bbl. daily. A few weeks later Grayburg Oil Co. Kimball No. 1, in the same sand, 7 miles west of the Pettus town site, at 3558 ft. made 244 bbl. of oil initially but later went to water. Since then six wells have been completed in this area without finding any more production.

Saxet and White's Point.—Although Saxet and White's Point, on either side of Nueces Bay, 6 miles west of Corpus Christi, have been producing gas for many years, it was not until August that the Saxet Oil Co., in its Dunn No. 6 at Saxet, and in December in Rachel No. 17 at White's Point, found oil. In Dunn 6, on the south side of the bay, the depth was 4304 ft. where 240 bbl. of oil, gravity 23.5° Bé, and 1000 bbl. of salt water were found; and in Rachel 17, at 4902 ft., 35,000,000 ft. of gas and 35 bbl. of 31° Bé. oil were found in December. Both these horizons are in the Frio and are probably closely equivalent to the shallow zone producing at Refugio.

Bee County.—Toward the close of the year, 3 miles northeast of the Pettus town site, the Union Producing Co. Ray No. 13, from a total depth of 3686 ft., made 200 bbl. initially, on a 9⁄32-in. choke, of 51° Bé. oil. The oil is from the upper part of the Cockfield formation and is apparently from the equivalent of the Pettus, or McKinney, sand. Previously Morgan had brought in a large gas well, McKinney No. 1, in Karnes County, 1600 ft. north of this well.

Goliad County.—In December, T. B. Slick et al., in Poetter No. 1, 21 miles northeast of Pettus, on the DeWitt-Goliad county line, from a depth of 4211 ft., produced initially 548 bbl. of 50.5° Bé. oil through 5⁄8-in. choke. This well is 20 miles from the nearest oil producer in Bee County and opens up considerable new territory. The sand is at the top of the Cockfield formation and is therefore probably the same as that producing at Pettus. This well is over 500 ft. lower structurally than Ray 13, which is about 20 miles southwestward but almost on the same strike.

Agua Dulce.—The Houston Oil Co. in its Comstock No. 1, 1½ miles east of the gas area, in December produced several million feet of gas and 100 bbl. of oil from a depth of 4913 ft., from a sand in the Frio formation. Agua Dulce has been producing gas since 1928.

Danbury.—The Shell Petroleum Corpn. Winston No. 1, at Danbury in Brazoria County, 32 miles south of Houston, after plugging back to 1579 ft. produced 124 bbl., half water. By July this well was flowing only 5 bbl. but it is considered a significant discovery. Danbury was found with the seismograph by the Shell company in 1928 and salt was topped in its Blakely-Winston No. 1, the first well to be drilled here, at 5221 feet.

Lassiter.—In the northwest corner of Brooks County, the Houston Oil Co. Wormser-Holbein No. 1 in February made 300 bbl. of 45° Bé. oil from 4150 ft. Although this well soon went to salt water it is of some significance, because the nearest production is in the Driscoll field in Duval County, 25 miles northwest.

New Flank Production on Old Domes

Humble.—The most important new flank production on old domes in 1930 was opened by the Sun Oil Co. Bender No. 3, on the west side of

Humble in January, from a depth of 3903 ft. The well made 2200 bbl. of 31.5° Bé. oil initially from the top of the Upper Saline Bayou formation of Upper Claiborne age. The nearest production from this same zone had been on the south side of the dome, 2½ miles distant. Since this discovery 23 wells have been completed and in March the production at Humble reached a new peak for recent years of 22,500 bbl., but had fallen to 12,000 bbl. by the end of the year. The wells to the south have not held up and the productive area is now limited to a strip 4000 ft. long.

Barber's Hill.—Barber's Hill has been by far the most active dome on the Gulf Coast during 1930. At the beginning of the year the production was 14,000 bbl. but a daily peak of 31,000 bbl. was reached in April and it is now making 24,000 bbl. Heterostegina lime production from 4800 to 5500 ft. was extended to the northeast flank by Humphreys, Fitzgerald No. 1; to the north flank by Bennett, E. W. Barber No. 3, to the northwest side by Humphreys, Barber No. 6-A; to the west side by Sun Oil Co., Winfree No. 1, and by numerous other intervening wells. Several of these wells have sustained their production remarkably well. The 6400-ft., or Lower Frio sand, found on the northwest side of the dome in 1929 has been continued to the west side by Yount-Lee in Fisher Nos. 1 and 3, and to the northeast side by Humphrey in Morgan No. 1, so that about 810 bbl. of the present daily yield from Barber's Hill is from this sand. The successful completion of wells in sands beneath an overhanging ledge of salt was initiated here in March, 1930, and since then 13 producing wells have been completed beneath salt. On the south side Bennett in Fisher-Higgins No. 2 found a new sand in the basal Miocene at 4761 ft., which produced 3000 bbl. initially in June. Since then five other wells have been completed in this sand and its present yield is about 1500 barrels.

Orchard.—In March, on the south side of the Orchard dome in Fort Bend County, the Gulf company found a new sand in Moore No. 20, which made 2300 bbl. of 28° Bé. oil from 3980 ft. Eight wells are producing from this sand and the production has been increased from 82 bbl. daily at the first of the year to 2000 bbl. at the end. This sand is Oligocene in age.

New Sand Discoveries

Refugio.—During April, 1930, the Refugio production reached a peak of 40,800 bbl. but declined to 29,000 bbl. at the end of the year. The heavy oil (3700-ft. sand, 26° Bé.) peak of 35,000 bbl. was reached in February and the light oil production from sands between 5400 and 6600 ft. attained a peak of 9500 bbl. in December. At the end of the year the field was producing 20,000 bbl. of heavy and 9500 bbl. of light oil.

During 1930 at Refugio, five apparently new oil-producing zones have been found. In March the Union Producing Co., M. F. Lambert No.

1, at 5884 ft., a new sand, yielded 1350 bbl. of 31° Bé. oil, and in June the Independent Oil Co. Helen Reilly was finished at 5665 ft. for 200 bbl. In July the Union Producing Co. Powers No. 4, at 5710 ft., was completed for 60 bbl. of gasoline. The Saxet Oil Co. Clint Heard No. 1 found production at 6386 ft., and later the Union Production Co., in Rose Lambert No. 1, found oil at 6468 ft., in probably the same horizon. This oil is 45° Bé. The deepest pay zone yet found is that in Moody-Seagraves' St. John No. 1 which was completed in December at 6644 ft. for 400 bbl. Twelve wells are producing from below 6300 ft. at Refugio. These deeper sands are all in the Frio formation.

The shallow or 3700-ft. sand at Refugio has fallen off rapidly during the year from a peak of 35,000 bbl. in February to 23,000 bbl. at the end of the year, because the wells sanded up and thus decreased their flow and the water increased. In December, L. L. Smith's Rogers No. 1, at 3648 ft., on the west side of the shallow area, one mile from the nearest production, was brought in to add to the probable shallow productive area. A total of 29 wells have been drilled at Refugio below 6000 ft. The Mission Oil Co. Moss Heard No. 1, at 8120 ft., is the deepest Refugio well, and even it had not yet reached the Jackson formation.

Esperson.—At the close of 1929, in the Esperson, or Sheeks field in southwest Liberty County, probably a deeply buried salt dome, Cranfill & Reynolds Vojdak No. 1A found significant gas with a spray of oil at 5752 ft. in the Lower Oligocene, and in July of 1930 at 7386 ft., in the Upper Saline Bayou of Upper Claiborne age, 10 bbl. of 36° Bé. oil was found. This later sand is a higher horizon than that from which at 7592 ft. Yount-Lee, Moore's Bluff No. 3, blew out, making from 20 to 50 million feet of gas. This well, after sidetracking, blew out again from a new sand at 7826 ft., also of Upper Saline Bayou age.

Gas Development in Texas Gulf Coast during 1930

In May, Nichols' Hicks No. 3 at Normanna, in Bee County, 8 miles south of Pettus, produced 15,000,000 ft. of gas and a little oil from 3647 ft. This comes from the top of the McElroy zone of the Jackson. Three miles north of Pettus, in April, Morgan's McKinney No. 1, from the Pettus sand at 3692 ft., produced 20,000,000 ft. of gas.

The Simms Oil Co. Holzmark No. 1, in Bee County, 11 miles southwest of Pettus, was completed in September for 50,000,000 ft. of gas at 3550 ft. Price's Weiss No. 1 got 2,000,000 ft. in a sand 100 ft. or more below the Pettus sand in Bee County 5 miles southeast of Pettus.

During 1930 a new producing horizon was found in the Edna gas field in Jackson County, at 3891 ft. in Wright's Drushel No. 7, and at Saxet in Nueces County, 6 miles west of Corpus Christi, two new gas sands were found: Thompson, in Lawrence No. 1 at 1732 ft., and the Saxet Oil Co. in Donegan No. 1 at 4091 ft. In the White's Point field on the north

side of the bay, at 4902 ft., 35,000,000 ft. of gas was produced with oil in Saxet Rachel 17.

The Houston Oil Co. Comstock No. 1, on the east side of the Agua Dulce gas field, in western Nueces County, is making considerable gas from a sand at 4913 feet.

Minor Developments

Texas.—In June the Humble Oil & Refining Co. found a very small pocket of gas and a little oil in Welder No. 1, at Nursery, 11 miles northwest of Victoria in Victoria County, at 5899 ft. in the top of the Cockfield formation close to the Pettus oil horizon. Mills-Bennett in Allen No. 1 found production on the Allen dome in February at 4930 ft. in a sand on the south side, and Poole No. 1, in October, after drilling through 508 ft. of brecciated anhydrite, produced from 4389 feet.

At Pierce Junction, the Rio Bravo, in its Settegast 12A, produced 1300 bbl. of 39° Bé. oil from a new sand at least 400 ft. in the Lower Oligocene. This is the first Lower Oligocene (Vicksburg) production at Pierce Junction. The depth of the well is 5504 ft. The same operator, a few days later, brought in Settegast 19A for 6200 bbl. of 35° Bé. oil from 4227 ft.; apparently a new sand for the south side of this dome. At the first of 1930 this dome was producing 11,700 bbl.; it reached a peak of 14,100 bbl. for the year in August but has dropped to 10,500 barrels.

In September, at Saratoga, the Rio Bravo found a new producing zone at 549 ft. in Cotton No. 90A, which made about 65 bbl. daily.

Louisiana.—Few developments of interest have occurred in Coastal Louisiana during 1930. Perhaps among the most significant has been a notable improvement in the production at Whitecastle and Black Bayou.

At Vinton, on the north side, substantial wells were found in a sand between 3400 and 3500 ft., in September, when Vinton Petroleum Co. Gray No. 7 made 3000 bbl. A still deeper sand, at 3631 ft., in this area, was developed by Wilson-Broach's Wilson No. 4. These sands are contributing about 1000 bbl. daily to the yield, which compares with a production of 4200 bbl. at the first of the year and a year's peak of 9900 bbl. in October.

At Sweet Lake, the Pure Oil Co. in Yount-Lee No. 9, at 6813 ft., a new deeper sand for this field, made 1270 bbl. of 28° Bé. oil. At East Hackberry, the Calcasieu Oil Co., in its Watkins No. 17, produced 1800 bbl. from 2706 ft., a shallow sand 1100 ft. above the old production, which is new to this field. Here, also, the Federal Petroleum Co. Hebert No. 1, in the south side, went to below 7800 ft., unsuccessfully.

At Bayou Bouillion, the Rycade-Humble's Atchafalaya Fee No. 5, from 4341 ft. produced 1600 bbl. of 37.5° Bé. oil in March. This is a new sand for Bayou Bouillion and occurs near the base of the Miocene formation.

At Jennings (Evangeline) in Acadia Parish, Yount-Lee's three 7400-ft. wells have continued to produce well. The third and latest of these was finished in June for 2000 bbl. of 35° Bé. oil. About 1200 bbl. of Jennings' total daily yield of 1800 bbl. is coming from this sand, which is in the Lower Oligocene. Yount-Lee's Houssière-Latreille No. 9, at 8651 ft., is the deepest Coastal well now drilling. The deepest dry hole on the Coast is also at Jennings—Texas Co. Rayne No. 5, which was finished in August at 8730 feet.

Production at Lake Barre, a dome close to the Gulf in Terrebonne Parish, and at Port Barre, the dome producing farthest inland on the Louisiana Coast, has been holding up remarkably well.

Salt Overhang

During 1930 the successful completion of 13 wells at Barber's Hill after they had gone into salt and then out of it into normal sediments has aroused great interest and has been the incentive to carry many wells, drilled on the flanks of other domes, for considerable distances into the salt before abandoning them, in the hope that an overhang may exist on these domes with profitable production beneath. Humphreys' Illfrey No. 2, finished in March, on the east side of Barber's Hill, was the first there to find oil below the salt. The salt was topped at 1503 ft. and passed out of at 2409 ft., and the well was finished as a 225-bbl. producer at 5087 ft. Since then salt has been found and passed through on the northeast, northwest, south and southeast sides. As much as 1551 ft. have been found in Mills-Bennett E. W. Barber No. 3 on the north side, and on the northwest flank, Humphreys' Barber No. 6 did not reach the salt until 3581 ft. and left it at 4361 feet.

On the north side of Vinton, in 1922, overhanging salt was proved but the oil sands below were poor and this occurrence does not seem to have had much influence on the practice of stopping wells in the salt.

On the south side of the Allen dome in Brazoria County, Mills-Bennett in Poole No. 1 penetrated anhydrite and calcareous sandstone from 1461 to 2086 ft. and later made an oil well at 4386 ft. It is doubtful whether this was really an overhung cap, but rather a brecciated or fingering zone of anhydrite in proximity to the flank of the dome.

The salt overhang has been variously explained by solution of the salt on the upper flanks of the dome; by the salt plug penetrating the sediments at an angle; by the weight of a thick overlying cap causing the salt to bulge at the top; and by squeezing due to the weight of impinging lateral sediments.

Petroleum and Natural Gas Development in the Rocky Mountain District, 1930

By R. Clare Coffin,* Denver, Colo.

(New York Meeting, February, 1931)

The production of petroleum in the Rocky Mountain district increased from 27,104,436 bbl. in 1929 to 33,048,630 bbl. in 1930. This increase was due to the development in southeastern New Mexico, which is in reality a portion of the West Texas province. Disregarding production in southeastern New Mexico, the Rocky Mountain district produced 25,799,027 bbl. in 1929 and 23,164,988 bbl. in 1930, a decrease of 2,634,039 bbl. for the period. The daily production in January, 1930, averaged 70,839 bbl. for the entire district and in December, 1930, the daily production was 98,995 bbl. Total production by states is given in Table 1.

Table 1.—*Total Production, Rocky Mountain District, by States*

State	Year	
	1929	1930
Colorado	2,273,577	1,596,139
Wyoming	18,997,509	17,695,942
Montana	3,895,949	3,278,941
New Mexico, Northwestern	632,002	593,966
New Mexico, Southeastern	1,305,399	9,883,642
Total	27,104,436	33,048,630

Three important discoveries of oil and one of gas occurred in the district during 1930 in structures not previously known to contain oil or gas. Oil was discovered in Dry Creek structure, Carbon County, Mont.; in the Midway structure, Natrona County, near Casper, Wyo.; and in the Greasewood structure, Weld County, Colo., northwest of Fort Morgan. Gas was discovered in the Bell Rock structure in Moffat County, western Colorado.

Seven deep tests in as many different fields encountered oil in lower horizons than those already exploited. All of these discoveries were in the state of Wyoming. They occurred in the Salt Creek field, Natrona

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County; in the Mule Creek and Lance Creek fields, Niobrara County; in the Lost Soldier field, Sweetwater County; in the Mahoney dome, Carbon County; in the Byron or Garland structure, and in the East Byron structure, Big Horn County.

The known reserves of oil and gas in the Rocky Mountain district were further increased by drilling in several areas. The important ones include Northern Montana in the vicinity of the Kevin-Sunburst field, where the further drilling in the Border field, Cutbank area and Sweetgrass hills met with some success and some disappointment; the Osage field in Weston County, Wyoming, which was extended by wells drilled west of the known area of production. Two other discoveries whose economic importance cannot yet be determined include the discovery of gas at Powder River station, Natrona County, Wyo., and oil in the Badger Basin dome in Park County, Wyoming.

The most important addition to known oil fields in the district took place in Lea County, New Mexico, where the Hobbs field was developed into a major oil pool. Other additions to the known oil and gas occurrences include the development in the Eunice, Copper and Jal areas, New Mexico, along the structural high extending northward into Lea County from the Winkler field. Further development also took place in the Lea and Getty pools in this same general territory.

Colorado

The production in Colorado decreased 677,438 bbl. during 1930 from the figure of the previous year. This is a drop of 29 per cent. for the period. All fields shared this decrease but it was especially noticeable in the Wellington and Florence fields, where the drop was more than 50 per cent. of the previous year's figure. A desire to conserve available oil is probably responsible for a large part of this decline.

New Discoveries

Greasewood Structure, Weld and Morgan Counties.—The outstanding development of the year in Colorado was the discovery of oil by the Platte Valley Petroleum Co. in its well near Orchard in sec. 24, T.6 N., R.61 W., Weld County. The well is on what has been known as the "Greasewood structure." On Oct. 10, 1930, the well encountered oil at a depth of 6638 ft. (corrected) and was ultimately deepened to 6644 ft. Up to Jan. 1, 1931, the well had flowed 14,802 bbl. of 41° gravity oil. This oil is now being trucked to Orchard, where it is shipped to the new Continental refinery at Denver.

The well has reached the basal beds of the Cretaceous formation and the oil probably is coming from the sands of the Dakota group, although definite proof of this is still lacking.

This discovery of oil is remarkable in that it is located in the Denver Structural Basin at a point not formerly thought to be of much interest both because of the extreme depth and the apparent lack of prominent structural features. Speculative values are added to a large portion of this part of Colorado because of this discovery. The leasing activity reached a maximum soon after the well came in and has continued up to the present time. A well being drilled by the I. T. I. O. in sec. 14, T.4 S., R.56 W., south of Fort Morgan in Morgan County is being watched with unusual interest.

Bell Rock, Moffat County.—On the Bell Rock structure in Moffat County, western Colorado, the Midwest Refining Co. well in sec. 4, T.6 N., R.92 W., encountered a flow of 35,000,000 cu. ft. of gas per day at 2867 ft. The beds supplying this gas are sandstones near the base of the Mesa Verde formation. Such a flow is unusual from this formation but inasmuch as the well is on a structure of considerable size it is probable that a fair-sized gas pool has been discovered.

Other Activity

Three items of interest are added bearing upon the gas development in the state during 1930.

Piceance Creek, Rio Blanco County.—The Magnolia Oil Co. completed a deep test of the Piceance Creek structure in Rio Blanco County to a depth of 5130 ft. Only shows of gas were encountered below that found near the base of the Green River formation at 2870 ft. The well was bottomed in beds within 500 ft. of the base of the Wasatch formation. Additional exploration is now being planned to test further the gas horizons near the base of the Green River formation.

North Park—McCallum Structure, Jackson County.—During the year the Dry Ice Corporation of America constructed a pilot plant at Walden, Colo. Experimental work was carried on with carbon dioxide gas from the McCallum structures in the manufacture of dry ice. Ten tons of the product were prepared during the tests. Other experimental work has been planned.

Berthoud Structure, Laramie County.—Three wells are now completed on the Berthoud structure in Laramie County to different depths where gas has been encountered in the Niobrara and Benton formations. One well has reached the Dakota formation and produces small amounts of oil. Between 4,000,000 and 5,000,000 cu. ft. of gas have been developed in the wells thus far drilled. Plans are under way whereby this gas will be utilized in the larger gas systems now supplying the near-by towns.

During the course of the year 20 wildcats in Colorado reached their objectives and were abandoned; 43 additional wildcats were active during

the summer but are now incompleted. Many have been shut down for the winter.

Wyoming

The production in Wyoming in 1930 showed a decrease of 1,301,567 bbl. from 1929, which was largely due to the decline in the Salt Creek field, where 11,312,094 bbl. were produced in 1929 and 10,514,844 bbl. in 1930.

The new discoveries in the State of Wyoming during 1930 by drilling deep wells to untested sands in known fields greatly overshadowed all other discoveries. No estimate can be made of the reserves of oil which have been discovered in these deeper sands in developed fields. In most instances the development in these deeper sands is limited to the discovery well drilled near the top of the structure, and in many cases even this single well has not been tested adequately.

New Fields and Extensions of Fields

Midway Dome, Natrona County.—The discovery of oil in wildcat structures within the boundaries of the State of Wyoming during 1930 may be limited to the operation of the Midwest Refining Co. and associated companies in their test of the Midway dome in sec. 23, T. 35 N., R. 79 W. Oil was encountered in the Second Wall Creek sand at 5157 to 5215 ft. and bottom water was encountered at the latter depth. The well, at its maximum depth, produced 400 bbl. of oil and 200 bbl. of water per day, and has been plugged back.

The behavior of this well and the presence of approximately 40 ft. of sand above the point where the water was encountered justifies the belief that at least a small oil pool is present in this horizon.

Badger Basin, Park County.—The Resolute Oil Co. (Peters Book et al.) drilling a well in sec. 17, T. 57 N., R. 101 W., on the Badger Basin structure, Park County, encountered the Second Wall Creek sand at 8250 ft. The well produced gas and some high-gravity oil but the significance of this discovery can be determined only by deeper drilling and the proper testing of the well.

Osage Field, Weston County.—The semiwildcat operations in the Osage field by the Osage Trust Co. and the Lambie Oil Co. extended the area of production northwestward for three consecutive years. The best well in this extension was drilled by the Lambie Oil Co. during 1930 in sec. 14, T. 46 N., R. 64 W. This well had an initial production of 540 bbl. per day. Thirty wells, completed in this new area during the last year, brought the Osage production from 238,602 bbl. in 1929 to 461,054 bbl. in 1930.

An interesting fact in relation to this field is that production started in 1920 and did not reach a peak until 1930.

It is important to recall in connection with this operation that the Osage field is an accumulation of oil due to the lensing of the Newcastle sand. This new development in the area is 300 ft. structurally below previously discovered oil and as yet no water line is established.

Deep Tests in Existing Fields

Salt Creek, Natrona County.—Oil was discovered in the Tensleep sand at a depth of 3790 ft. in a well drilled by the Midwest Refining Co. in the N. W. ¼ sec. 35, T. 40 N., R. 79 W. The amount of oil increased with continued drilling to a depth of 3870 ft. where water was encountered. At this point the well flowed approximately 1500 bbl. of oil of which the gravity is 27.7°. The Tensleep oil was cased off and the test continued to the granite at 5420 ft. In drilling the Madison lime an enormous flow of 132,000 bbl. of water having a temperature of 183° was encountered at 4605 ft. No oil was encountered below the Tensleep sandstone.

Lance Creek, Niobrara County.—The Sundance formations in the Lance Creek field are now known to contain oil. The Ohio Oil Co., drilling in the southeast corner of sec. 32, T. 36 N., R. 65 W., cored sand from 3653 to 3660 ft. The well flowed 330 bbl. of 36° oil in 16 hr. It is estimated that the well can produce 600 bbl. per day. The horizons producing this oil can be definitely correlated with the Second Sundance of the Salt Creek field. The peculiar interest to be attached to this discovery is the fact that no Sundance oil had been found previously in this general area.

Mule Creek, Niobrara County.—A deep test drilled by the Argo Oil Co. in cooperation with the Robert E. May and Ohio Oil companies encountered oil in the Minnelusa formation at 3162 ft. An additional 8 ft. was drilled without materially increasing the amount of oil and the well now stands practically full of 27° gravity oil. No effort has been made to test the well at this depth. The location of this test well is in sec. 19, T. 39 N., R. 60 W. Although not adequately tested this appears to be a commercial discovery of oil. If so, it will be the first to be found in beds of this age in the Black Hills province.

Lost Soldier Field, Sweetwater County.—The discovery of oil by the Prairie Oil and Gas Co. in the Tensleep sand in the Lost Soldier field is probably the most important discovery during the year made by deep tests in known fields in Wyoming. The oil is 35° gravity and contains approximately 1.2 per cent. sulfur. Prior to this discovery such a grade of oil had never been found in quantity in the Tensleep formation. The Tensleep sandstone was reached at a depth of 3940 ft. and after a short test was rated as a 1500-bbl. well.

Mahoney Dome, Carbon County.—The Producers and Refinery Corpn. (Prairie Oil and Gas Co.), drilling a well jointly with the Midwest Refining Co. on Mahoney dome, encountered oil in the Tensleep formation at a

depth of 4600 ft. After drilling 83 ft. into the Tensleep a pumping test showed 70 bbl. of 34° gravity oil per day. Further exploration will be necessary before the importance of this discovery can be determined.

Byron or Garland, Big Horn County.—The Ohio's deep test on the Byron structure in sec. 33, T. 56 N., R. 97 W. found the Madison limestone to be productive. The oil is 19.2° gravity with a 3 per cent. sulfur content, being similar to that found in this formation in the Oregon Basin and Frannie fields. Such a discovery adds much interest to exploration in this horizon in near-by structures when there is demand for such oil.

The Ohio well previously had produced 58,000,000 cu. ft. of sour gas when tested at a depth of 3893 ft. At this depth approximately 400 ft. of the Madison formation had been tested. Many contend that the Embar, Tensleep, Amsden and top of the Madison all contributed gas to this well.

At a depth of 4427 ft. the well had penetrated approximately 934 ft. of the Madison formation and was here tested for oil. It flowed approximately 230 bbl. in 1 hr. and was then shut in. Estimates give 2500 bbl. as the capacity of this well. Because of the size of the Byron structure a tremendous reserve of low-grade crude is suggested by this discovery. Because of the gravity of the oil and the depth at which it is found the immediate economic importance is questioned.

East Byron, Big Horn County.—The Tensleep sand was found to contain oil in the East Byron structure when tested by the Ohio's deep well located in sec. 22, T. 56 N., R. 97 W. The sand was cored from 5337 to 5409 ft. and after testing for a short period by different methods, estimates were made that it could produce 730 bbl. per day by pumping. The oil has a gravity of 25°.

Development of Natural Gas

The reserves of natural gas were increased during the year in three places in addition to the discovery already reported on the Powder River dome.

Baxter Basin, Sweetwater County, Wyo. and *Hiawatha, Moffat County, Colo.*—During the last year three wells were completed to the gas-producing horizon in the south Baxter Basin field and one in the north Baxter Basin field. A total of 23 gas wells now exist in the Baxter Basin-Hiawatha district distributed as follows: Hiawatha and west Hiawatha,[1] 7; south Baxter Basin, 13; north Baxter Basin, 3. All of these wells are on the property of the Mountain Fuel Supply Co. except the one on south

[1] West Hiawatha dome, sometimes referred to as Bartram dome, is a separate high on the main Hiawatha structure. The major portion of this structure lies in Colorado.

Baxter Basin owned by the Wyo-California Co. and one in the west Hiawatha field owned by the Texas Company.

The pipe line now extending from this district into Utah supplies Green River, Lyman, Evanston, Salt Lake City, Ogden and small intermediate points.

Pilot Butte, Fremont County.—During the course of the year the well previously drilled by the Kinney-Coastal on the Pilot Butte structure in sec. 22, T. 3 N., R. 1 W., was deepened and ultimately plugged back to the gas-producing horizon. During 1929 the well reached a gas sand, probably the Muddy, at 3348 ft. The metered flow of gas at this depth was 63,000,000 cu. ft. per day. Ultimately the well was deepened to the Sundance horizons without additional gas or oil being found and it was then plugged back. Presumably during this entire operation additional Muddy sand was drilled in addition to that first encountered, as the metered flow after plugging back was approximately 100,000,000 cu. ft. Because of its isolation, no immediate outlet exists for this gas.

Big Sand Draw, Fremont County.—The Producers and Refiners Corpn. has drilled a deep test below the known gas horizons in the Big Sand Draw field. Sands of the Dakota-Lakota group have been penetrated at a depth of approximately 4217 ft. Sands from the basal portion of this group contributed small amounts of gas and the first Morrison sand, which was encountered at approximately 4290 ft., contributed a great volume of gas which has not been gaged. The estimated flow is between 50,000,000 and 60,000,000 cubic feet.

Montana

Montana produced 3,895,949 bbl. of crude oil during 1929 and 3,278,941 bbl. in 1930, a decrease of 617,008 bbl., or approximately 15 per cent. for the year. All existing fields showed about an equal decline, which was partly neutralized by production from Bannantyne and Border fields. During December, 1930, the new Dry Creek field in Carbon County was added to the list of producers.

Drilling activity within producing fields was held to a minimum during the year and the Pondera field was prorated for a portion of the period, both factors contributing to the decreased production.

New Oil Development

Dry Creek, Carbon County.—The discovery of oil in the Dakota formation at Dry Creek by the Ohio Oil Co. is the most important to be made in the state since the discovery of the Kevin-Sunburst field.

During 1929 the Ohio Oil Co. proved the existence of commercial gas in the Second Wall Creek sand in this structure and during 1930 this

company discovered oil in sands of the Dakota-Lakota group at a depth of 5412 ft. Two thousand barrels of 48° gravity oil is the estimated capacity of this well.

The Dry Creek structure is so badly faulted that it is impossible to predict accurately subsurface conditions. However, surface mapping indicates approximately 1500 ft. of closure which, when taken into consideration with the production of the initial well, suggests the importance of this discovery. Approximately 500 bbl. of oil was being marketed daily from this initial well in December, 1930.

Border, or Red Coulee, Toole County.—Thirty-one wells had been drilled in the Border field up to December, 1930. Eight of these were dry and abandoned. The remaining 23 wells had a daily production during December of 611 barrels. The important factor controlling the accumulation of oil in this field appears to be the lensing character of the sands of the basal Jurassic, which produce the oil. Offset wells do not record the same sands nor do they encounter the same material in the sands when present.

No definite closure can be mapped by the subsurface data supplied by wells thus far drilled. However, a prominent structural nose extends northwest through the area of maximum production. Structurally the oil in this field is 800 ft. down on the northwest side of the main structural high of the Kevin-Sunburst field.

Gas Development

Cutbank Area, Glacier County.—During 1930 a serious effort was made to develop a gas area north of Cutbank in T. 34 to 36 N., R. 5 and 6 W. The record of wells drilled in this general area to date shows that five wells encountered gas in amounts ranging from 1½ to 15 million cubic feet. The horizons producing the gas include the "stray" Ellis and Sunburst sands. Three wells are now drilling in the area. Presumably the distribution of the sands in the lower Jurassic determines the presence or absence of commercial gas.

Sweetgrass Hills, Toole and Liberty Counties.—Three wells were completed in the immediate vicinity of the Sweetgrass Hills during 1930. The Western Natural Gas Co. encountered 9,000,000 cu. ft. of gas in the Sunburst sand at a depth of 2063 ft. The well was located in sec. 23, T. 37 N., R. 4 E., in what is known as the Whitelash area. In September a pipe line from this area was connected to lines serving Great Falls.

The Sunburst Oil and Refining Co. drilled a well in the Bears Den in sec. 18, T. 36 N., R. 6 E., and 5,000,000 cu. ft. of gas was encountered in the basal Colorado formation at a depth of 2325 ft. The well encountered 25 bbl. of oil per day in the "stray" Ellis sand.

The F. & F. Oil Co. drilled in sec. 12, T. 33 N., R. 1 E., and encountered 4,000,000 cu. ft. of gas in the Colorado sands at 737 ft.

To date 14 wells have been drilled in and around the Sweetgrass Hills which have reported gas discoveries ranging in volume from 1½ to 15 million cubic feet per day and shows of oil up to 38 bbl. per day. This oil and gas was encountered in sands of the Colorado group and in the so-called "stray" Ellis and Sunburst sands.

Bowdoin and Baker Glendive.—Gas development during the year in the state of Montana included continued operations of the Minnesota Northern Power Co. in the Bowdoin and Baker-Glendive areas. Several wells were drilled on the Bowdoin structure to develop the shallow gas found in the sands and sandy shales of the Colorado formation at depths ranging from 800 to 1000 ft.; 19 wells are reported as capable of producing during the year. Gas lines extend west from this field to Malta, a distance of approximately 20 miles, and eastward approximately 38 miles to Glasgow.

During 1930 the Minnesota Northern Power Co. extended its gas lines from near Baker in the Baker-Glendive field in southeastern Montana eastward along the main line of the Northern Pacific R. R. to Bismark, N. D. The largest towns served on this line are Dickinson, Hebron, Mandan and Bismark. Another extension by this company northward from Glendive to Williston, N. D., also serves Sidney and Fairview, Mont. A third line is a 25-mile extension from Marmouth, N. D. to Rhame and Bowman, N. D. on the Chicago, Milwaukee and St. Paul R. R. This line will probably be extended eastward in 1931.

A 480-hp. compressor station has been recently completed at Cabin Creek in the Baker-Glendive field to compress gas for the Bismark, Williston and Miles City lines. An additional 320-hp. compressing capacity was added to the station at Baker for compressing gas for the Black Hills and Bowman lines. Gas from this field supplies towns in the Black Hills area as far south as Rapid City, South Dakota.

New Mexico

Northwestern Part

Production in the northwestern part of the New Mexico province for the year was 593,966 bbl. The Hogback field showed a slight increase and the Rattlesnake and Table Mesa fields showed a slight decrease. It is interesting to note that the deep test of the Continental on the Rattlesnake structure still produces approximately 200 bbl. of oil per day with back-pressure on the well. A second deep well is now being drilled on this structure. No other drilling occurred on these structures during the year.

During the year the Southern Union Gas Co. completed a gas trunk line from the Southern Ute gas structure in northwestern New Mexico to Albuquerque and Santa Fe.

Southeastern Part

The importance of southeastern New Mexico as a producer of crude oil is indicated by the increase in production for the past four years, which is indeed phenomenal. In 1927, the production was 607,498 bbl. and in 1930, it was 9,884,346 bbl. This portion of New Mexico is to be classed as one of the most important parts of the Wext Texas province.

The development at Hobbs overshadowed all other activity in the area. Further development, however, has taken place along the eastern edge of Lea County, especially in the Jal and Eunice areas. Inasmuch as the Lea pool was not prorated during the year its production is an important factor.

Hobbs Field, Lea County.—The Hobbs field has had a phenomenal development during the past year as indicated by the fact that it produced only 73,936 bbl. in 1929 and 6,646,766 bbl. in 1930. This production is 69 per cent. of the total for this portion of the state for this year.

In January, 1930, eight wells had been completed in the Hobbs field with an estimated capacity of 13,900 bbl. On Jan. 1, 1931, according to the official prorate schedule, 137 wells had a potential capacity of 1,081,411 bbl. The average daily pipe line runs on the latter date were 31,430 bbl., approximately 3 per cent. of their total rated capacity.

The field can now be outlined as including approximately 10,000 acres of productive oil land.

The first pipe line runs from this field were on May 8, 1930, by the Humble Pipeline Co. Since that date the Atlantic Pipeline and Shell Companies have extended their lines to the field.

On July 16, 1930, the Hobbs pool went on a proration basis with a field allowance of 35,000 bbl. per day. This allowance is divided on the Yates field plan, 75 per cent. according to the potential of the wells and the remaining 25 per cent. among the 40-acre units which are productive.

The average well to Jan. 1, 1931, had produced 50,434 bbl. of oil and had a rated potential of 7318 bbl. Ten wells have been drilled in this field which were given a rated capacity, after the usual test of over 20,000 bbl. per day.

The occurrence of the oil in the Hobbs field as it can now be outlined is limited rather definitely by structure. Wells that encounter the "white lime" at an elevation of −600 ft. are dangerously near the water line. This same bed was found at an elevation of −343 in the Shell well drilled in the southwest corner of N. E. ¼ sec. 32, structurally the highest thus far drilled.

Production in the field is coming from the so-called "white lime" found in west Texas. Approximately 200 ft. of this formation probably will be found productive on the top of the dome. Because of the fact

that proration became effective early in the life of the field and because of the methods of running tubing in the wells, a high recovery per acre is predicted. This recovery should compare favorably with the big oil fields of west Texas.

Eastern and Central Lea County.—The development along the eastern edge of Lea County has been along the western edge of the gas-producing area already partly outlined for the territory. It was assumed that oil would be found more or less continuously along the edge of the gas-producing area. Up to the present time the development has been somewhat disappointing in that the zone between the gas above and the water below, in which oil should occur, has been found to be narrow and somewhat erratic. However, the wells drilled to date in the Eunice, Cooper and Jal areas prove that oil will be found at many spots adjacent to the gas area along this structural high.

During the course of the year 1,857,568 bbl. of oil were produced from the Lea pool. This is a remarkable record in view of the fact that only nine wells have been drilled. Although all wells in the Lea pool are pumped the remarkable production per well and the lack of a proration accounts for the production.

During the year over 4½ billion cubic feet of gas was delivered from the Jal area to the lines of the El Paso Natural Gas Co. for consumption in El Paso.

Eddy County.—An increase during the year is reported in the production of the Maljamar pools (sometimes referred to as the Jackson pool). The decrease in the Artesia production is approximately normal for the wells now producing. Very little added drilling took place in the Artesia field during the year.

In the Getty pool production has been limited to that which can be disposed of as a road oil after the lighter fractions have been removed by a skimming plant.

Proration and Shut-in Production

Proration, as ordinarily applied to oil production in the Rocky Mountain region, was limited to the rigidly supervised scheme of operation in the Hobbs oil field.

For a large portion of the year production in the Pondera field in Toole County, Montana, was curtailed to approximately 80 per cent. of its rated capacity and in many fields wells existed which were not produced to capacity but were limited to a rate of production that has been determined by experience to be good practice for the conditions existing there.

Outside of the southeastern corner of New Mexico the production of so-called light oil in the Rocky Mountain region was practically at capacity for the year. In several fields controlled by single companies

production was limited to current demand, which was less during 1930 than during 1929. In other fields the decrease in 1930 production is due to the natural decline of wells already drilled.

The term "shut-in" production as applied to the black-oil reserves needs special explanation. In black-oil fields which have been supplying a current demand, such as Oregon Basin and Hamilton dome, a prediction of the oil reserves may be made with assurance. Again, the "shut-in" production in such fields can also be stated with some precision. In other cases where a black-oil reserve has been proven by a single wildcat well the term "shut-in" production has no particular meaning.

In the Rocky Mountains there are several isolated structures which have been tested by a single well to the black-oil bearing horizons. Because of their isolation and lack of pipe line facilities no tests have been made and the oil is not available for immediate demand.

The sum total of all of the estimated potential production from all wells which have now been drilled to the black-oil bearing horizons in the Rocky Mountain region on all structures is probably significant. The grade of such oil ranges from a 15° gravity found on the North Sunshine field to a 29° gravity crude in Hamilton dome.

The estimated "shut-in" production of all black-oil wells drilled in the Rocky Mountain region, not including southeastern New Mexico, prior to December, 1930, is approximately 29,000 bbl. During the month of November, 1930, the average daily production from all of these wells totaled 5326 bbl. It is obvious that a substantial reserve of low-grade black oil is proven by the operations now completed in the Rocky Mountain region.

Summary

Three new light-oil fields have been discovered in the Rocky Mountain region during 1930.

The Dry Creek discovery in Montana is probably of great importance. The presence of oil in the Greasewood structure in northeastern Colorado opens up a large area for exploration. Because the occurrence of this oil is in a province where structural features are not supposed to be prominent, this discovery may be something new in oil accumulation for the Rocky Mountain province.

Although of less immediate interest, the oil reserves suggested by the deepening of wells in existing fields during 1930 are probably of greater extent than those existing in the three newly discovered light-oil fields.

Several of these deep-sand discoveries are of unusual interest. The presence of oil in the Sundance formation at Lance Creek is new for that territory, also the occurrence of oil in the Minnelusa formation at Mule Creek is something new for this stratigraphy in the Black Hills

province. The presence of 35° gravity oil had never been suspected in the Tensleep sandstone until the discovery was made in this sand in the Lost Soldier field. The discoveries of black oil in the Madison formation in the Byron structure suggest that this horizon will be found productive in other undrilled structures in the area.

The development of the Hobbs oil field in New Mexico is the outstanding feature in the region.

Petroleum Developments in California during 1930

By B. E. Parsons,* Los Angeles, Calif.

(New York Meeting, February, 1931)

Curtailment of production of crude oil, to the extent of effecting an approximate balance in supply and demand, was a problem confronting the oil industry in California throughout the year 1930. At the beginning of the year, with drilling operations only slightly checked, the California industry faced a steadily increasing potential production, an actual production in excess of market requirements and stocks of crude oil and refined products which had reached staggering proportions. During the year, the intensive development of the Playa Del Rey field and extensions to several oil fields, together with flush production from numerous large wells from both new and old fields, caused a steady increase in the state's potential production to a record peak in November of 1,186,000 bbl. daily.

Despite the burden of this steady stream of flush production and the handicap of incomplete cooperation in several fields, curtailment successfully lowered the trend of crude oil production in California, except for the period of an open-flow test to determine actual potential production in several important fields in February. Under the curtailment programs in effect, the state's production of crude oil for the year was reduced 22 per cent. under the production of 1929 and even slightly under the production for the years 1927 and 1928. The total stocks of crude oil and refined products were reduced 2.7 per cent. during 1930, as compared to an increase of 30 per cent. in total stocks of all products during 1929.

Drilling operations were reduced 28 per cent. as compared to drilling activities during 1929. Voluntary curtailment of drilling programs by many operators, particularly the major companies, accounts for the greatest portion of the reduction in drilling activity. The decline in drilling activity at Santa Fe Springs and in the east-side fields of the San Joaquin Valley was more than offset by development in new fields and extensions to deeper zones of old fields. There were 755 new wells completed during 1930, as compared to 910 completions in 1929. At the close of the year, 220 wells were drilling in the oil fields of California, 9 of which were being drilled in search of deeper producing horizons.

* General Petroleum Corpn. of California.

The intensive campaign of wildcat and exploratory drilling started in 1929 as the result of the discovery of high-gravity oil in Kettleman Hills and at Elwood was continued during the early months of 1930. Failure of many deep tests to show favorable results, and the general policy of major oil companies, in particular, in reducing drilling operations to a minimum during the period of overproduction, caused a material decrease in the number of wildcat and exploratory wells drilling throughout the state in the closing months of the year.

Wildcat activities have followed closely the trend of operations in 1929. In the coastal counties of Ventura, Santa Barbara, San Luis Obispo and Monterey, they have been confined wholly to areas underlain by rocks of the Lower Miocene and Oligocene age. In the San Joaquin Valley, wildcat drilling has been carried on, not only in areas where Vaqueros and Temblor sands of the Lower Miocene were considered to hold possibilities for production but also in areas where possibilities for production have been considered favorable in sands or sandy shale zones in the Santa Margarita formation. During the year, many structures have been definitely eliminated from further consideration by the drilling of wildcat wells. At the close of the year, there were 19 wildcat wells drilling in the Los Angeles Basin; 22 in the Coastal districts and 23 in the San Joaquin Valley. Wildcat operations were also being carried on in 24 counties in central and northern California; 42 wells were actively drilling in these counties at the close of the year. While several of these wells have encountered showings of oil or gas and some have produced a few barrels of high-gravity oil, no commercially productive fields have been discovered as a result of the recent drilling activities in the central and northern part of the state.

Significant Developments during 1930

In the San Joaquin Valley: (1) High-gravity oil was discovered in Temblor sands in the North Belridge field; (2) there was renewed activity in search for deeper production in the Lost Hills field; (3) normal high-gravity crude oil was discovered in the Kettleman North dome field; (4) oil was discovered in Santa Margarita sands in the Mountain View area south east of Bakersfield.

In the Los Angeles Basin: (1) A deeper producing zone was found in the West Coyote field; (2) deep zone extensions were developed in the Long Beach field; (3) production at Playa Del Rey rose to more than 48,000 barrels per day.

In the Coastal district: (1) The westward extension of the Elwood field was extended into the ocean; (2) the productive thickness of the producing oil zone in the Ventura Avenue field was extended; (3) the westward extension of Rincon field was proved into the ocean; (4) a probable eastward extension of the Lompoc field was discovered; (5) there were developments at Capitan, eight miles west of Elwood.

A large amount of exploration work was carried on in California during 1930, particularly in the Coastal and San Joaquin Valley districts. Geophysical methods of exploration, which had been used extensively during previous years, were on the decline throughout the state during 1930, for the reason that the application of these methods had not resulted in the finding of new fields. The use of airplane photographs for geological base maps had become so general that in several cases companies have shared the expense of making photographs of a single large area. One area of 2200 square miles was photographed by six companies in this manner.

Core-drilling equipment and surveying instruments have continued to gain in favor with the operators, and a combination of core barrel and surveying machine designated to orient cores, and thus determine dip and strike of beds, has been used with some success.

During 1930, there has been continued improvement in the technology of drilling, particular attention being given to the design of rig structures and of equipment for the handling of deep and high-pressure wells. The Standard Oil Co. of California's Mascot No. 1, near Taft, the deepest hole in the world, was drilled to a depth of 9629 ft. in April, 1930, and a string of 5⅝-in. casing was cemented about 9350 feet.

General producing methods have improved. Wells are being pumped successfully just short of 8000 ft., and pumps operating at 7500 ft. are common. Gas injection in partly depleted zones has been practiced in several fields with beneficial results.

The California State Gas Conservation Act, which became effective in August, 1929, did not afford any great measure of relief during 1930. Legal contests in connection with injunction proceedings under this Act, for the Santa Fe Springs, Long Beach, Ventura and Kettleman Hills fields, finally resulted in affirmation by the Courts of the constitutionality of the Act late in the year. Appeals from the Court decisions rendered, however, have further delayed the enforcement provisions of this Act.

San Joaquin Valley District

Total production of San Joaquin Valley fields for 1930 was 53,996,309 bbl., an increase of 4,526,936 bbl. over production for 1929. The Midway-Sunset field alone contributed 43.5 per cent. of the total valley production. Substantial increases in the production from the Kettleman North dome, Round Mountain and Fruitvale fields, accounts for the overall increase in the total production from valley fields.

Drilling activities in the San Joaquin Valley were materially decreased during the year through completion of the development campaign in the Maricopa Flat area of the Midway-Sunset field, and the voluntary curtailment of drilling programs in all east-side valley fields. There were 152 wells completed in all fields in 1930, as compared with a total of 241

wells completed in 1929. At the close of the year 42 wells were drilling in all valley fields, with the greatest activity centered in the Belridge and Kettleman Hills North dome fields.

Discovery of high-gravity oil in Temblor sands in the North Belridge field was the outstanding feature of the exploratory drilling campaign carried on in west-side fields during 1930, in a search for production from the Vaqueros and Temblor horizons. Well 15 of the Belridge Oil Co., sec. 26, T. 27-S, R. 20-E, was completed in October, 1930, at a depth of 5457 ft. Initial production of the well from the 500 ft. of producing zone was 3000 bbl. of 46.0° gravity oil and 60,000,000 cu. ft. of wet gas. Increasing steadily in production, the well produced on Dec. 31, 1930, 4375 bbl. of 43.7° gravity oil and 32,000,000 cu. ft. of wet gas. Completion of the discovery well started an active drilling campaign in the Belridge district and at the end of the year there were 12 wells drilling to the Temblor zone, 11 in the North Belridge area and one in the northwestern portion of the South Belridge field. The resultant drilling projects have not reached sufficient depth to furnish information necessary for an estimate of the probable extent of producing area in the North Belridge field.

Following a preliminary flow test on well 15 in April, two exploratory wells were started in the Lost Hills field. Universal Consolidated well No. 49 on sec. 32, T. 26-S, R. 21-E, at the close of the year had reached a depth of 4913 ft. and had cored 39 ft. of oil sand in the Temblor zone. A string of 9-in. casing was cemented above the sand, but apparently had failed to exclude the flowing hot salt water encountered about 100 ft. above the oil sand. While there has been no production from the sand penetrated, the demonstration of the presence of oil sand in the upper measures of the Temblor formation seems to give reasonable assurance that ultimately commercial production will be developed in the field from this or some lower measures in the Temblor formation.

A gradual drilling program in Kettleman North dome field resulted in completion of four new wells and the recompletion of one well deepened during the year. All wells brought into production were on fee lands, since the agreement between the Department of the Interior and certain operators in the field limited production to a minimum on lands covered by the agreement. During the year, two wells were completed on Government leases and closed in after a short flow test.

The outstanding feature of the year's operations was the proving of the existence of a normal high-gravity crude oil in the Temblor horizon in the Kettleman North dome, through greater penetration of the horizon and at a position on the structure outside of the area of gas concentration. Ochsner 20 well No. 2, of the General Petroleum Corpn. of California, completed in June, 1930, at a depth of 7691 ft., penetrated the Temblor formation for 1400 ft., the greatest thickness of producing zone developed

in any well in the field. A short flow test on this well demonstrated the presence of a low-gravity crude oil in sands below the 900-ft. portion of the horizon previously developed in other wells. Evidence of core records substantiated this important development.

Superior Huffman well No. 1, the most notable completion of the year, was drilled to a depth of 8323 ft. having penetrated the Temblor formation 1258 ft. This well was drilled on sec. 29, T. 21, R. 17, at the northwest end of the field, and encountered the top of the producing horizon approximately 1000 ft. structurally lower than the discovery well. Producing from practically the entire thickness of the zone penetrated, the well produced initially 7400 bbl. of 40.1° oil and 55,000,000 cu. ft. of gas, demonstrating the presence of a normal high-gravity crude oil in the Temblor horizon outside of the area of gas concentration. A 20-day flow test indicated that the well was capable of producing in excess of 15,000 bbl. daily. An important feature in connection with this well is that it is producing at an oil-gas ratio of less than 3000 cu. ft. per barrel as compared to oil-gas ratios of 20,000 to 40,000 cu. ft. in other wells.

Realizing the tremendous potentialities of the Kettleman North dome field and the necessity for the orderly development, operators concerned have made a determined effort during the year to devise a plan for the unit operation of this important oil and gas field. As the year closed, agreement had been reached on such a plan and documents pertaining to it were being prepared for signature.

An important development in the south end of the San Joaquin Valley was the discovery of oil in Santa Margarita sands in the Mountain View district, 10 miles southeast of Bakersfield. Shell Co. Porter-Day Well No. 1, in sec. 29, T. 30, R. 29, was completed in November at a depth of 5910 ft. The well produced 1160 bbl. of 21.3 gravity oil and 550,000 cu. ft. of gas. After a short flow test, the well was killed and drilling operations were resumed to prospect for deeper production. At the close of the year, the well had reached a depth of 6702 feet.

The status of other fields in the San Joaquin Valley district has remained unchanged during the year. Several deep test wells drilled in the Midway-Sunset, Elk Hills and Wheeler Ridge fields failed to develop any production below known zones.

Los Angeles Basin District

Fields in the Los Angeles Basin produced 137,595,248 bbl. of oil, or over 60 per cent. of the State's total production for the year 1930, with four fields—Santa Fe Springs, Long Beach, Huntington Beach and Seal Beach—contributing 72 per cent. of the production.

Drilling activities during the year were confined principally to the Santa Fe Springs, Long Beach and Playa Del Rey fields, which contributed

456 of the total 508 producing wells completed in the basin during 1930. Development operations in other fields, except for a few deep tests, were either suspended or greatly reduced during the year.

Santa Fe Springs, since the completion of the Union Bell well in October, 1921, has produced about 306,000,000 bbl. of oil, or about 200,000 bbl. per acre. The deeper zones, Nordstrom, Buckbee, O'Connell and Clarke-Hathaway, have produced 111,750,800 bbl. of the field's total production, since the discovery of the Buckbee zone in July, 1928. Producing under curtailment, except for a short period in February and March, the field registered a production of 44,268,952 bbl. for 1930, and was again a dominant factor in the state's production. The intensive drilling campaign to deeper sands, which was in progress at the beginning of 1930, continued during the first quarter of the year. Progressive definition of the productive limits of the deeper zones caused a rapid decline in drilling activity during the remainder of the year. Many wells that were started for the deeper zones, particularly the Clarke-Hathaway, were forced back to produce from upper zones, either because of unfavorable position on structure or failure to secure commercial production at time of completion. Three deep tests have discouraged prospecting to any depth under 9500 ft. Despite curtailment, wells producing from the deep zones, particularly the Clarke-Hathaway zone, have shown a marked decline in production during the year. The majority of the wells are now being produced by means of the gas-lift or are being pumped. The close of the year finds the field producing about 74,000 bbl. per day, which is fully 40 per cent. under the potential production of the field.

The status of the major portion of the Long Beach field has remained unchanged throughout 1930. Considerable competitive drilling was carried on in the extreme southeast and northwest portion of the fields and a large number of wells were completed in the latter, or Los Cerritos, area, in deep sands not heretofore developed in that part of the field. While many of the new wells had initial productions ranging a high as 1200 to 1500 bbl. daily, all have shown a rather sharp decline in production. The flush production from 142 new wells completed in the field during the year has more than offset the normal decline of the old wells. The production of the field has ranged steadily around 100,000 bbl. daily throughout most of the year, resulting in a total production for the year of 36,749,400 bbl. Greater curtailment reduced the field's production to a daily average of 94,000 bbl. during the month of December.

The Playa del Rey field, lying between Venice and Playa del Rey, was brought into the production picture through the completion of the Ohio Oil Co. Recreation No. 1 well in December, 1929. Development operations progressed slowly during the first three months of the year. The Ohio Oil Co. Recreation Well No. 2, completed in May, 1930, at a

depth of 6154 ft. for a daily production of 1580 bbl. of 24.5° gravity oil, was the second producer in the field. Granting of permits for drilling in the town-lot area started an intensive town-lot drilling campaign which reached a peak in October with over 100 wells actively drilling. Wells are producing from two zones, one between the depths of 3400 and 4500 ft. and the other between the depths of 5800 and 6200 ft. The upper zone in characterized by thin sands and shale and the lower zone by a nodular shale body and conglomerate sand. Wells in the lower zone have had greater initial productions but have declined more rapidly, probably on account of the character of the formation, which gives up the oil more readily. Water is showing in considerable quantity in many of the wells in the lower zone; this also has probably been a cause for greater decline in the lower zone production. During the year 155 wells were completed within an area of 200 acres. The completion of a large number of wells during the months of October and November developed a production in excess of 48,000 bbl. daily in the early part of December. During the month of December the field registered a decline of production—the average daily production for the last week being 41,635 bbl. At the close of the year, there were 59 wells drilling, 137 wells producing and 18 idle producers. While Playa del Rey's total production for the year was only a small percentage of the state's total production, the amount produced was sufficient, in view of the refusal of operators to curtail their output, seriously to complicate the overproduction problem. Cheap crude available to local independent refiners was a disturbing factor in the marketing end of the industry in the Los Angeles Basin throughout the last half of the year. It is probable that the posting of a market price for Playa del Rey crude on December 18, appreciably higher than prices received during the year, may prove some incentive for operators in this field to cooperate in the state-wide curtailment movement.

Except for a slight revival of drilling activity in the town-site portion of the Potrero field, conditions in other fields in the Los Angeles Basin have remained unchanged throughout the year except for measures of curtailment applied to the more important fields. The production of all fields except Potrero was reduced below the level of production for 1929. The Potrero field produced 638,268 bbl. in 1930 as compared to 271,446 bbl. in 1929. The initial production of new wells in the Potrero town-lot area has ranged as high as 1000 to 2500 bbl. daily, but all have declined rapidly and many are producing high percentages of water.

Probably one of the most important developments in the Los Angeles Basin fields during the year was the discovery of a deeper producing zone in the West Coyote field, approximately 2000 ft. below the top of the main producing horizon. The Standard Oil Co. Emery well No. 43-A was completed at a depth of 5735 ft. in January, 1930. This well produced at a rate of 1500 bbl. daily, 31.2° gravity oil, for a few days and

was then shut in. The Standard Oil Co. Murphy well No. 105 in the same field is drilling below a depth of 5200 ft. and four additional new wells are scheduled for drilling to the deep zone.

Several deep test wells were drilled in or near the East Coyote, Santa Fe Springs, Huntington Beach, Dominguez and Torrance fields, but did not result in extending the productive acreage, the thickness of known zones, or the discovery of deeper zones.

In the Rosecrans field, Sunset Pacific's well No. 31 was drilled to a depth of 7500 ft. but failed to find any productive horizon below a depth of 5450 ft. The initial production of this well was 800 bbl. daily with some water, from a zone between 5250 and 5435 ft. This is not a new discovery, as the zone had been cored previously in other wells but not produced. Production from this horizon probably will be confined to a limited area on top of the structure.

Deep tests worthy of mention, still drilling at the close of the year, are: Shell Co. Manuel No. 7, in the Dominguez field, drilling at a depth of 8536 ft.; Continental Oil Co. Selover-McGrath No. 24, at Seal Beach, drilling at 8071 ft. and Superior Oil Co. Fee No. 1 and McCaslin well No. 1, drilling at 7425 and 7100 ft. respectively in the Huntington Beach field. Wildcat activities in the Los Angeles Basin have failed to uncover any new producing areas during the year.

Coastal District

Total production from Coastal fields in 1930 amounted to 36,206,342 bbl., an increase of 1,119,537 bbl. over the production for the previous year. Ventura Avenue and Elwood fields contributed 88 per cent. of the total production from Coastal fields. Curtailment of production in the Ventura Avenue field and natural decline in the smaller fields was more than offset by the increased output of Elwood, which accounts for the slight increase in total production for the year.

The decrease in drilling activity in the Ventura Avenue field was offset by the increased activity at Elwood and in smaller fields. In all, 95 new wells were completed in Coastal fields in 1930 as compared to 97 new producers in 1929. The Ventura Avenue field registered 36 new completions and the Elwood field 31 completions during the year.

Activities at Elwood were featured by the erection of costly piers and submarine foundations for the development of the westward extension of the field into the ocean. A steady but slightly competitive drilling campaign carried on during a portion of the year developed a potential production in excess of 100,000 bbl. daily. Several new wells completed during the year had initial productions ranging from 10,000 to 14,000 bbl. per day. During the year, the field produced 14,606,007 bbl., an increase of 5,170,619 bbl. over the production in 1929. The daily average of

34,621 bbl. in December was fully 65 per cent. under the field's potential production. Drilling was reduced 50 per cent. in the closing month of the year.

In the Ventura Avenue field, Taylor well No. 46, belonging to the Shell Co., drilled to a depth of 7136 ft., developed a production of 875 bbl. daily from a 200-ft. zone not heretofore penetrated by any other well in the field. This discovery is important, as it indicates possibilities for developing still deeper zones of production in this field. Two wells are being drilled to test the "Taylor zone" at other locations on the structure. Production of the Ventura Avenue field was maintained at a fairly uniform rate, the daily average for the year being 47,927 bbl. A steady but conservative drilling campaign developed a potential production in excess of 97,000 bbl. daily in December, 1930, the highest potential in the history of the field. The development of a peak potential 13 years after the discovery of the field is rather remarkable, and has resulted from the conservative development policy pursued during the last six years, which has had as its object the orderly development of the deeper zones and not the sudden development of a large production.

At Rincon, nine miles west of Ventura, the completion by the General Petroleum Corpn. of Ferguson well No. 2 on a State Tideland permit at a depth of 3447 ft. for an initial production of 1039 bbl. of 29.0° gravity oil, definitely proved the westward extension of the Rincon field into the ocean. The Ferguson well is located 1700 ft. off shore and 2300 ft. west of the nearest on shore well, and is producing from the Miley zone between depths of 3065 and 3400 ft. A test on sands of the upper zone encountered between depths of 2540 and 2580 ft. showed production of 500 bbl. daily. Piers and foundations for three new wells were practically completed as the year closed.

In the Lompoc district, the Vaqueros Major Oil Co. well No. 1, drilled one mile east of the Lompoc field, developed production from an eastward extension of the producing zone of the old field. Well No. 1 was completed at a depth of 2987 ft. in July, 1930, and pumped, at the rate of 600 bbl. daily, 22.0° gravity oil for a few days and was then closed in on account of lack of storage. Drilling operations of the Vaqueros Major Oil Co. wells 2 and 3 were suspended during December, 1930.

Following the discovery of oil in the Vaqueros sand at a depth of 1300 ft. at Capitan, eight miles west of Elwood, late in 1929, a potential production of 1200 bbl. daily was developed in this sand from eight wells in 1930. At the close of the year, General Petroleum Corpn. Erburu No. 8 had been cored entirely through the Sespe formation to a depth of 4071 ft. and is preparing to test light oil sands cored in the Sespe between depths of 2300 and 2700 feet.

Status of the Santa Maria, Casmalia, Cat Canyon, Summerland, and older fields in Ventura County has remained unchanged during 1930.

Deep test wells in the Santa Maria and Cat Canyon districts failed to discover deeper zones of production.

A large number of wildcat wells drilled on anticlinal and fault structures underlain by the Vaqueros and Sespe formations in the coastal counties have definitely eliminated many structures from further consideration and no new commercially productive areas were discovered as the result of this activity.

Production Curtailment

The tremendous effort of leaders of the oil industry in California to reduce the crude oil production of the state, while not wholly successful in effecting a balance of supply and demand, resulted in a very substantial decrease in the crude output for the year. Benefits of reduced production are reflected in crude oil prices.

Measures of curtailment have been applied during the year to every important field of the state except Playa Del Rey.

The cooperative curtailment programs established in the Santa Fe Springs, Long Beach, Ventura and Elwood fields in 1929, were continued during January and February of 1930. There being need for greater curtailment of crude oil production, a state-wide curtailment program was instituted on March 1, 1930, under direction of a General Committee. This Committee set the allowable production of the state at 609,000 bbl. daily on March 1, and subsequently reduced the allowable quota to 596,000 bbl. daily on May 16, to 540,000 bbl. daily on Sept. 1st, and to 500,000 bbl. daily on Dec. 18, 1930. Failure to reduce the state's daily production to the allowable quotas, together with a steadily increasing state potential and an increasingly lower demand during the latter months of the year, forced the successive lowering of the state's quota by the General Committee. Under the programs of curtailment in effect during the year, the state's production of crude oil was lowered from 707,137 bbl. daily in January, to 573,765 bbl. daily in December. Greater curtailment in December reduced the state's production to 537,500 bbl. daily during the last few days of the year, the lowest production recorded for the state since February, 1923.

Results obtained to date, from curtailment of California's oil production, may be seen in Fig. 1, which is self-explanatory.

Production

California's production for the year totaled 228,099,899 bbl., a daily average of 624,931 bbl. This is a total decrease of 63,937,012 bbl., or 175,170 bbl. daily under the production of 1929. Los Angeles Basin fields contributed 60.46 per cent., San Joaquin Valley fields 23.67 per cent., and Coastal fields 15.87 per cent. of the state's total crude oil production

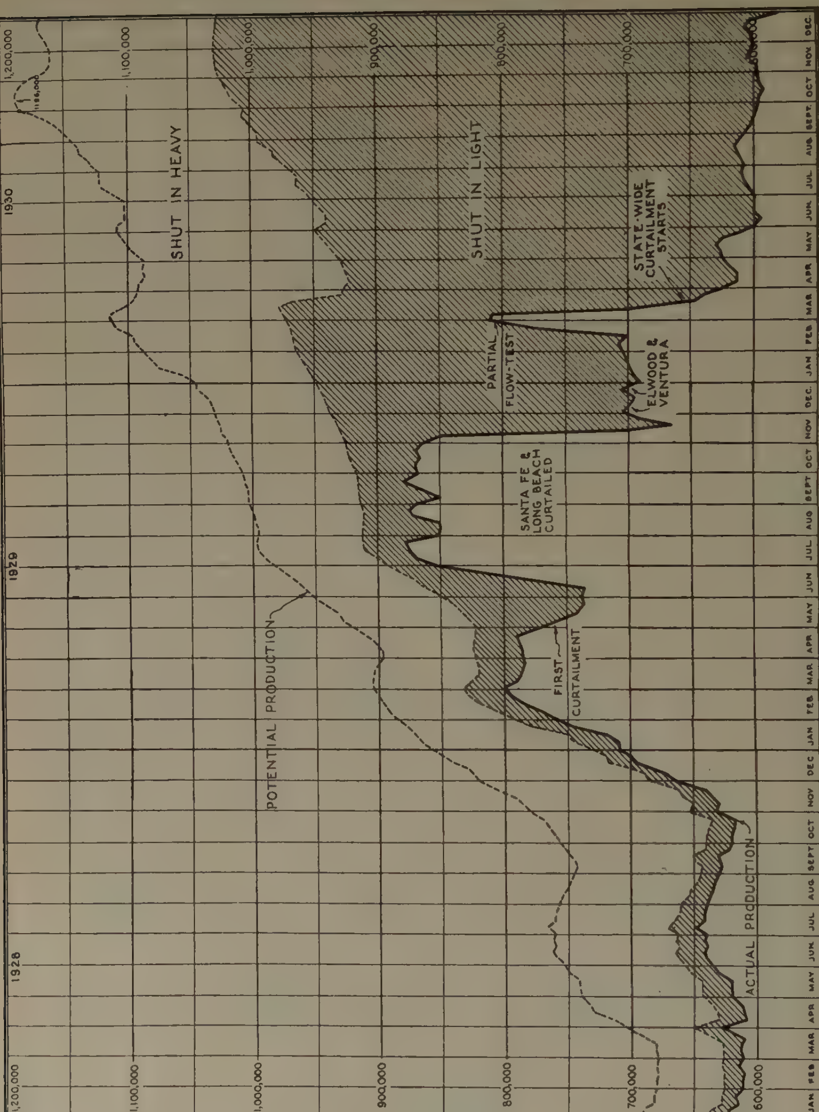

FIG. 1.—PRODUCTION AND CURTAILMENT IN CALIFORNIA.
Production according to A. P. I. reports. Potential for 1930 according to official estimates of Fact Finding Committee.

for the year. Table 1 shows the total yearly production of crude oil by fields for the years 1929 and 1930.

TABLE 1.—*Total Yearly Production of Crude Oil in California*
A. P. I. Figures

Fields	Total Production 1930, Bbl.	1930 Percentage of State Total	Total Production 1929, Bbl.	1929 Percentage of State Total
Santa Fe Springs	44,251,396	19.400	76,477,464	26.187
Long Beach	36,599,688	16.045	60,495,555	20.715
Midway Sunset	23,487,147	10.297	25,310,976	8.670
Ventura Avenue	17,493,155	7.669	20,934,388	7.168
Elwood	14,606,007	6.403	9,435,819	3.231
Huntington Beach	11,108,203	4.870	16,007,030	5.481
Seal Beach	8,026,796	3.519	14,418,305	4.937
Elk Hills	6,572,379	2.881	6,353,035	2.175
Inglewood	6,429,205	2.819	8,768,101	3.002
Kettleman Hills	6,209,357	2.722	1,951,786	0.668
Kern River	5,349,915	2.346	6,089,344	2.085
Playa del Rey	4,719,981	2.069	25,121	0.008
Fullerton	4,423,266	1.939	4,813,942	1.648
Torrance	4,116,846	1.805	5,000,218	1.712
Coyote Hills	3,890,047	1.706	4,176,035	1.429
Mount Poso	3,883,924	1.703	1,826,056	0.625
Dominguez	3,694,075	1.619	3,606,850	1.235
Richfield	3,643,578	1.597	5,776,258	1.977
Coalinga	3,373,078	1.479	3,558,843	1.218
Montebello	2,712,725	1.189	3,657,922	1.252
Rosecrans	2,435,341	1.068	2,463,808	0.843
Ventura-Newhall	1,772,131	0.777	1,856,706	0.635
McKittrick	1,489,628	0.653	1,708,520	0.584
Lost Hills-Belridge	1,313,475	0.576	1,602,425	0.548
Round Mountain	1,194,832	0.524	223,734	0.076
Santa Maria	1,152,893	0.505	1,535,815	0.525
Rincon	1,003,204	0.440	1,192,237	0.408
Fruitvale	903,337	0.396	594,498	0.203
Potrero	638,268	0.280	271,446	0.092
Los Angeles-Salt Lake	545,959	0.239	552,614	0.189
Whittier	516,802	0.226	563,790	0.193
Wheeler Ridge	219,237	0.096	250,156	0.085
Lawndale	130,472	0.057	392,533	0.134
Summerland	118,042	0.052	93,826	0.032
Capitan	25,295	0.011	2,795	0.001
Watsonville	22,764	0.010	22,762	0.007
Newport	14,600	0.007	15,330	0.005
Santa Barbara	12,851	0.006	10,868	0.003
	228,099,899	100.000	292,036,911	100.000

Stocks

Total stocks as of Dec. 31, 1929, were 184,817,317 bbl., the greatest total in the history of the California industry. Increases in refinable crude, gasoline and naphtha distillate stocks during January and February, 1930 caused an increase in total stocks to a new record high of 189,698,723 bbl. on Feb. 28, 1930. During succeeding months and up to September 30 there was a decrease in stocks of all products. A slightly

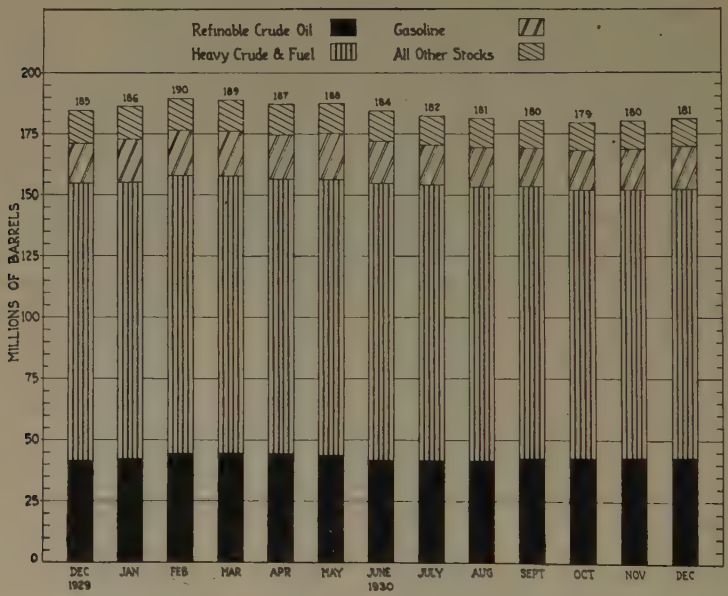

FIG. 2.—PACIFIC COAST STOCKS AT END OF EACH MONTH.

lessened demand for gasoline and reduction in crude runs to stills caused an increase in gasoline and refinable crude stocks during the last quarter of the year. Total stocks, as of Dec. 31, 1930, were 181,033,141 bbl., a decrease of 3,784,178 bbl. during the year (Fig. 2).

Stocks of heavy crude, heavier than 20° A. P. I., including all grades of fuel, were decreased 3,766,499 bbl. Stocks of refinable crude, 20° A. P. I., and lighter increased 1,275,033 bbl., gasoline stocks increased 710,741 bbl.; naphtha distillate increased 314,686 bbl. and all other stocks decreased 2,118,139 barrels.

Prices

California petroleum prices since 1919 are shown on Fig. 3. Owing to the wide ranges in quotations, the curves are averages, and representative of the trend and the changes in prices quoted, rather than a record of actual prices.

Two general revisions were made in crude prices during the year 1930. The first, March 11, 1930, was a substantial increase in prices for the higher gravities, increases ranging from 3¢ per barrel for 21° gravity to 25¢ per barrel for 30° gravity oil. On Sept. 15, 1930, there was a general adjustment in prices to slightly lower levels. Prices for heavier grades of crude have been maintained at a slightly higher level throughout most of the year.

Kettleman Hills crude was put on a gravity scale Sept. 15, 1930. Prices established ranged from $1.10 to $1.65 per barrel. Prior to this

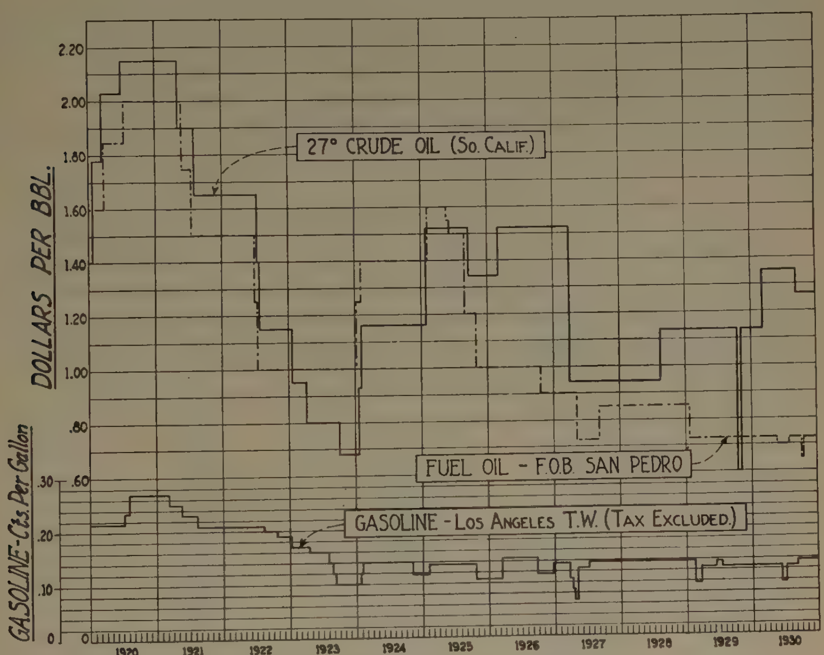

FIG. 3.—PETROLEUM PRICES, CALIFORNIA.

date, the price for Kettleman crude was $1.65 per barrel. Prices for crude oil at Playa Del Rey were not put on a gravity schedule until Dec. 18, 1930, prices posted ranged from 74¢ for 20° gravity to 90¢ for 25° gravity oil.

An interesting feature of the course of crude oil prices during 1930 is that these changes were made during a period in which potential production was steadily rising in California. The absence of curtailment or other restrictive measures during this time, not only would have made such a trend in prices impossible, but it is more than likely prices would have dropped through the low levels of previous periods.

The course of fuel-oil prices was influenced throughout the year by burdensome stocks while shipments off coast were exceedingly light.

Some shipments were made at a price of 50¢ per barrel. A further depressing factor during the latter part of the year was the fuel oil derived from the Playa del Rey field and its effect on the local market. As very little fuel oil has been shipped to the east coast since the fall of 1929, price decreases during 1930 reflect a local condition rather than any depressing influence exerted by other areas.

The third curve shows the trend of gasoline prices in the domestic market. Gasoline prices were influenced by a price war which first developed in the late spring and reached a climax during the summer with service station prices as low as 5¢ and 6¢ per gallon. The curve for the latter part of 1930 indicates a fairly satisfactory condition although price cutting has not been eliminated, particularly in Southern California and Pacific Northwest districts. In the Los Angeles district, gasoline is being retailed as low as 12½¢ per gallon (tax included), as against a posted price of 20½¢.

ACKNOWLEDGMENTS

Acknowledgment is made to R. O. Swayze, General Petroleum Corpn. of California, for assistance rendered in preparation of this report. The production and curtailment chart was furnished by R. E. Allen, Assistant Umpire; the stock and price charts were prepared by E. J. Siebert, General Petroleum Corpn. of California.

Petroleum and Natural Gas in Canada during 1930

By Linn M. Farish,* New York, N. Y.

(New York Meeting, February, 1931)

The reported production of petroleum in the Dominion of Canada for 1930 was 1,555,199 bbl., an increase of 458,373 bbl. over 1929. Alberta accounted for nearly all the production with Ontario and New Brunswick, the other two productive provinces, contributing less than 1 per cent. of the total. The completion of about 25 producing wells in Alberta was more than sufficient to offset the decline of the older wells in that province and the small decline in Ontario. The production of about 5000 bbl. in New Brunswick represents a restricted output to meet the market demand.

Table 1 shows the production by provinces for the past 10 years.

Table 1.—*Petroleum Production of Canada,* 1921–1930

Year	New Brunswick, Bbl.	Ontario, Bbl.	Alberta, Bbl.	Total, Bbl.
1921	7,479	172,859	7,203	187,541
1922	7,778	164,732	6,559	179,069
1923	8,826	159,399	1,943	170,168
1924	5,561	154,317	844	160,722
1925	5,376	144,249	177,783	327,408
1926	5,812	136,971	291,598	434,381
1927	24,562	139,606	332,133	496,301
1928	7,164	134,164	489,531	630,859
1929	7,731	121,125	967,970	1,096,826
1930	5,350	116,506	1,433,343	1,555,199
Totals	85,639	1,443,928	3,708,907	5,238,474

The consumption of natural gas for all purposes in Canada reached a new record of practically 40,000,000,000 cu. ft. in 1930, which was a considerable increase over 1929. The estimated value of the gas output was $10,500,000, against a little over $5,000,000 for the total petroleum production. Gas wells in Alberta accounted for over 75 per cent. of the total, with Ontario second and New Brunswick a poor third.

The outlook for 1931 is for very little change in production of either gas or oil in Ontario and New Brunswick but for a substantial increase in both in Alberta.

* Foreign Department, Henry L. Doherty & Co.

New Brunswick

The petroleum and natural gas produced in the Province of New Brunswick come from a field in Albert County, about 9 miles south of the city of Moncton.

The production is obtained from sandstones interbedded with shales in the Albert series which are Mississippian in age. The field developed to date is approximately 3½ miles long by 1 mile wide and is generally considered to be a structural terrace upon the flank of an anticline.

About 100 holes have been drilled in the field of which 27 are now producing gas and 20 are potential oil producers, most of which are closed in pending the erection of refining facilities. The present average depth of the gas wells is between 2000 and 2500 ft. while oil is encountered between 2500 and 3000 feet.

The city of Moncton and the town of Hillsboro are connected with the field by gas pipe lines, a 10-in. line, 8.3 miles in length having been constructed to Moncton while a 4-in. line 3.9 miles long supplies Hillsboro. The average yearly gas consumption is 630,000,000 cu. ft. and the present open flow of the field is about 10,000,000 cu. ft. per day. The largest well had an initial capacity of about 17,000,000 cu. ft. per day. The gas is dry, with a specific gravity of 0.679 at 60° F. and a heating value of 1130 B.t.u. per cubic foot.

The oil wells are small producers, the largest initial production being about 100 bbl. per day, but have a very slow decline. The oil has a paraffin base and a gravity of 38° Bé. On distillation it yields 17 per cent. gasoline, 21.7 per cent. kerosene, 11.1 per cent. gas oil, 36 per cent. lubricating oil and 11.6 per cent. petrolatum.

Ontario

Oil and gas have been produced for many years on the Ontario peninsula between Lake Huron and Lakes Erie and Ontario. The romance of the pioneer work in such fields as Oil Springs, Petrolia and Sarnia is well known and the technique developed in this area has affected the petroleum industry the world over.

As early as 1830 the presence of oil was reported in Enniskillen township, Lambton County. In 1858 a hand-dug well encountered oil at 100 ft. and in 1861 or 1862 a well was drilled to a depth of 165 ft. where a flow of over a thousand barrels was attained. The commercial production of Ontario dates from the drilling of this well.

In 1881 the production of the Ontario fields was in the vicinity of 350,000 bbl. The peak production was between the years 1888 to 1901 when approximately 750,000 bbl. per annum were recovered. Since 1901 there has been a gradual decline until 1930 when the production was not quite 120,000 barrels.

The value of the gas production in 1892 was $150,000 and increased steadily to 1918 when it was over $3,500,000. The settled consumption is now about 7,500,000,000 cu. ft. per year valued at approximately $4,000,000.

Alberta

The Turner Valley field, in the belt of greatly disturbed rocks along the Rocky Mountain front about 30 miles south of Calgary, continued to overshadow all other developments not only in Alberta but in all of Canada. During the year several additional wells were completed with most of the development toward the southern end of the field.

In November, 1930, the field had 61 producing wells, 12 dry and abandoned, 31 drilling, and 46 suspended or shut down. Most of the last named group will probably not be completed.

The principal producing horizon, a porous zone in limestones of probably Mississippian age found at depths of 3400 to 6000 ft., was discovered in 1924. The production record since that year is given in Table 2.

Table 2.—*Production of the Turner Valley Field*, 1925–1930

Year	Production, Bbl.	Year	Production, Bbl.
1925	177,783	1928	481,357
1926	291,598	1929	950,039
1927	332,133	1930	1,364,584

The wells in the Turner Valley field yield large quantities of gas which is very rich in naphtha of 60° to 75° Bé. gravity. Nearly all the production is of this high-grade naphtha which is separated from the gas mechanically. A small portion of the gas is marketed in Calgary, but most of it is burned in the field to get rid of it. A considerable content of hydrogen sulfide makes it necessary to scrub the gas before it can be utilized. About 50,000 bbl. of a light crude was produced in 1930 from sands above the limestones from which the gas and naphtha production comes.

Outside Turner Valley, tests in the foothill belt were unsuccessful in finding oil production. Most of them showed extremely complicated geological conditions due to the overthrusting which accompanied the elevation of the front ranges of the Rocky Mountains immediately to the west. One well in the Moose Mountain district west of Calgary, starting stratigraphically below the productive horizon in Turner Valley is reported to have developed considerable gas from a limestone well down in the Paleozoic section, probably in the Devonian. A well in the intricately faulted and folded region southwest of Pincher

Creek, in the southwestern part of Alberta, had a flow of 4,000,000 to 5,000,000 cu. ft. per day from a sand, probably in the Kootenai formation. Whether or not these wells indicate the discovery of important fields can not be told as yet.

There was very little activity in the Plains region as a whole, the one exception of any importance being the development of the Red Coulee or Border field on the International boundary west of Couts, Alberta and Sweetgrass, Montana. By the end of October, 1930, this field had four producing, eight abandoned, and two drilling wells. The production for that month totaled 6615 bbl. The wells range between 20 and 80 bbl. per day initial production. The oil is from 30° to 32° Bé. gravity and comes from lenticular sands in the Dakota-Kootenai and Ellis formations at an average depth of about 2500 feet.

There was no change of importance in the Wainwright, Irma and Ribstone fields, to the southeast of Edmonton, which produce gas and small quantities of heavy oil from Lower Cretaceous sands at depths around 2000 ft. The individual wells yield as high as 100 bbl. per day of 16° Bé. oil for which there is little demand at present. In October, 1930 the Wainwright field had seven producing, two abandoned and 27 drilling and suspended wells. The Ribstone field had four producing (shut-in) wells, three abandoned and three locations. The heavy crude production for 1930 amounted to practically 15,000 barrels.

Natural Gas in Alberta

Natural gas is widely distributed in Alberta. The old fields in the southern part of the province, Medicine Hat, Foremost and Bow Island, were developed several years ago but still produce some gas into the pipe-line system that connects these fields with Calgary. Two gas wells (Rogers-Imperial and Dead Horse Coulee) on a well-defined structural nose running north from the Sweetgrass Hills in T. 1, R. 11 W. of the 4th meridian and one well (Ericson Coulee) on a similar structure in the township to the west promise considerable supplies of gas for the extreme southern part of the province. The Viking gas field, in the same general area as the Wainwright and Ribstone oil fields southeast of Edmonton, supplies Edmonton with gas through an 80-mile pipe line. There are 20 producing wells with a total open flow of 108,000,000 cu. ft. per day with a rock pressure of 600 lb. per sq. in. One well at Kinsella, 12 miles east of the Viking field, was brought in with an open flow of 24,000,000 cu. ft. per day and 700 lb. rock pressure in 1929 but there was no further drilling in 1930. The town of Wainwright is supplied with gas from a field near Fabyan. Still other localities have shown the presence of gas but lack of market has prevented development.

The Turner Valley field is estimated to have an open flow of more han 300,000,000 cu. ft. per day. This great supply of gas, most of

which is being wasted, together with the developed and prospective fields mentioned above, has led to much discussion and several proposals for pipe line systems to carry Alberta gas to Regina, Saskatoon and other cities in Saskatchewan and even as far as Winnipeg, in Canada, and also to the Spokane and Puget Sound regions in the United States, but nothing final along this line was accomplished in 1930.

The total amount of gas produced and consumed in Alberta, including. that used for field operations and in refineries, was 31,816,800,000 cu. ft. The total production, including the gas wasted in Turner Valley, is estimated at more than 10 times this amount, about 360,000,000,000 cubic feet.

Acknowledgments

Acknowledgment for information furnished is made to Messrs. J. A. L. Henderson and A. Crichton, for New Brunswick; to Mr. R. B. Harkness for Ontario; to the staff of the Supervisory Mining Engineer at Calgary, and to Messrs. Robert Hill, S. E. Slipper, William Pearce, L. D. M. Baxter, T. A. Link and P. D. Moore for Alberta.

DISCUSSION

(*H. J. Wasson presiding*)

H. J. Wasson,* New York, N. Y.—Before taking up these papers covering the specific countries, just a word of attempt to correlate the whole foreign situation briefly, which as we all recognize is becoming more and more important. For instance, in 1929 the United States had 67 per cent. of the world's production; in 1930, 63½ per cent.; and in 1931 it is estimated at around 52½ per cent. We are all more or less familiar with that trend—the trend of the balance of the world gradually supplying more and more of its own production.

We are not all so familiar with the fact, which is rarely emphasized in these summaries, that the United States' domestic demand is a substantially smaller percentage—possibly on the order of 57 per cent. with respect to the rest of the world at 43 per cent. Yet the United States produces 62½ per cent. That indicates, of course, that the United States has a net export balance in its favor in the world's commerce.

The important countries of the world in 1930 were United States, Venezuela, with Russia a very close third, and then two or three of about the same size—Persia, Mexico and the Dutch East Indies and Rumania. Those six or seven countries comprise the bulk of the world's production. There are 15 or 20 others, and we have papers specifically covering most of the important countries.

O. B. Hopkins,† Toronto, Ont.—All the wells that produce naphtha from gas carry back-pressures which vary from 500 upward, but generally range from 800 to 1100 lb. There is one interesting feature—each one has a critical back-pressure under which it will produce most efficiently. That may be 600 lb. in one well and 1100 lb. in another; but speaking generally, in the newer areas where the wells are tapping a virgin part of the field, greater efficiency is obtained by using the higher back-pressures. The back-pressures are carried to the separators, into which the gas is allowed

* Consulting Engineer.

† Chief Geologist, Imperial Oil, Ltd.

to expand. The chilling effect produced and the reduced velocity cause the naphtha to separate from the gas.

V. R. Garfias,* New York, N. Y.—One point in regard to these fields that is worth mentioning is the freezing of the oil or gas or the water in it and the great difficulties encountered to bring the frozen wells back to production. I certainly would like to get some light on this interesting production-engineering problem.

O. B. Hopkins —In the type of foothills structure described in my paper on The Rocky Mountain Structure in Alberta,[1] most of the folds that have been drilled deep enough have proved the presence of an underlying thrust fault, below which are younger beds than those immediately above or even those at the surface. In one case at least, drilling has shown beds under the thrust that are younger than those at the surface. The nature of these folds is still a debatable question but I am rather inclined to the opinion that most of the folding that we see is really a drag effect along a fault plane, rather than a fold that has actually developed into a strong fold and then faulted.

One reason for believing this is that deep drilling on these folds has suggested that they either have no downward continuation, or, if they have, the upper part of the fold is offset to the east from such downward continuation. To how great an extent the upper and lower parts of the folds are offset by thrusting is not known, but it must amount to miles rather than hundreds of feet. The drag along such thrusts appears to be a logical explanation of many of the folds; also, the general absence of unfaulted folds indicates the importance of faulting in the area.

The Turner Valley structure is the most easterly fold in that part of the foothills. Most of the structures that have been tested are located along the margin between the foothills and the plains. Further back towards the mountains, the structures are, generally speaking, more involved; they are more intensely faulted and folded. Faults cut this area into a number of blocks of variable size which are more or less folded but dip generally to the west. The chances of finding production in these areas are rather remote.

L. C. Snider,† New York, N. Y.—I first had the idea that all of the folds were drag folds. From my own work (not in the Turner Valley area, but farther south) I almost came to the conclusion that there is little drag folding but that the folds were tightly compressed, generally overturned, and then faulted as the pressures continued. In the Benton shale, there is about as much disturbance along faults of 50 ft. displacement as along much greater ones. It appears that considerable bending and contortion takes place before slickensided surfaces develop, but that after these are developed the sliding of one block over the other may go to great distance with no more disturbance of the shale and no formation of drag folds. The slickensided zone acts as a lubricating layer between the two blocks.

Member.—What is the oil and gas ratio?

L. C. Snider.—I cannot give the ratio exactly but it would be very large. The production is a naphtha-bearing gas and not oil. The recovery of naphtha per well per day has been as high as 600 or 800 bbl. I do not remember the gas production of those wells. Probably Mr. Hopkins would know that.

O. B. Hopkins.—In the early history of the wells, 1 bbl. of naphtha was recovered from 35,000 to 40,000 cu. ft. of gas. As the wells get older the ratio increases, and

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* Foreign Department, Henry L. Doherty & Co.

[1] Read before Geological Society of America. Not yet published.

† Consulting Geologist, Henry L. Doherty & Co.

many of the wells today are producing 1 bbl. of naphtha for 120,000 to 160,000 cu. ft. In other words, the gas is getting drier as the wells get older. Probably an average at the present time would be 1 bbl. of naphtha from 80,000 cu. ft. of gas.

No system of spacing has been actually worked out. Drilling has been concentrated in parts of the field where the ownership is in small lots; in these areas it appears that about four wells have been drilled where one would have been sufficient. I should say that probably one well to 160 acres would be the proper spacing if the right spot in the limestone were encountered in drilling.

MEMBER.—Has the amount of gas dropped in pressure in proportion to the age?

O. B. HOPKINS.—No, many of the wells produce, under slightly altered back-pressures, practically the same amount of gas today that they did originally. The gas volume is practically the same but its naphtha content is declining.

H. J. WASSON.—The rise in Canadian production in 1930 was marked from the percentage standpoint and I would be interested in knowing what the prospects are for the immediate future. Have they a very large order of magnitude or has it about reached its balance, for a time, anyway? There is an active wildcatting campaign going on, I understand, both along this foothill belt and farther out to the eastward in the plains region. I wonder what the views are as to additions to the larger distance to the productive area.

O. B. HOPKINS.—The foothills drilling has fallen off at the present time as compared with what it was a year or so ago. I think it probably reached a maximum a year and a half ago during the big boom we had out there. The money has been largely spent and there is not much more forthcoming for further wildcat drilling in the foothills.

There have been many serious disappointments where the structures looked attractive and very much like Turner Valley, but in the course of drilling and before the limestone is reached the ubiquitous fault is encountered, with the result that the drill enters on its under side a higher formation than the one above, and in some cases higher than the formation at the surface.

H. J. WASSON.—I thought that was what the geologists were supposed to foresee.

O. B. HOPKINS.—It is difficult for the geologist to find a location where a thrust fault may not be present to upset his calculations. There are a few interesting tests in the plains being drilled at present but so far as they have gone there is nothing encouraging to report.

H. J. WASSON.—What is the individual production record of the largest well, Royalite No. 4?

O. B. HOPKINS.—Royalite No. 4 has produced around 950,000 bbl. of naphtha.

H. J. WASSON.—Is it still going strong?

O. B. HOPKINS.—No. In that particular well the original gas-naphtha ratio was about 1 bbl. of naphtha per 33,000 cu. ft. of gas; today it is 1 bbl. of naphtha per 130,000 cu. ft. of gas, and the production instead of being around 600 bbl. reaches on some days a maximum of 100, but averages around 60 or less.

A. O. HAYES,* New Brunswick, N. J.—If I may be permitted to give a note of both pessimism and optimism, without having worked in this field since 1920, I should

* Professor of Geology, Rutgers University.

like to say that I then examined the foothills, all the way from the international boundary to Calgary, and noticed that the limestone when hit with a hammer gave off the odor of petroleum. That is, that the Paleozoic limestone is bituminous where it outcrops from beneath the Mesozoic strata in the foothills, and it seems quite logical that this faulted structure should produce oil and gas.

As one goes over into the plains and reaches over into the other side of the Great Plains area in the vicinity west of Lake Winnipeg, he finds again some evidences of oil over in the eastern areas; also some oil shale. It looks rather dubious that the deep-lying limestone under the plains probably not so greatly faulted would be as prolific of gas and oil as in the greatly shattered foothill structure, and yet is it not possible that in some places under the plains there may have been buried ridges, or there may have been coarser materials interbedded with the limestones from which some oil may yet be found? Since oil shale of Paleozoic age occurs west of Lake Winnipeg and the bituminous limestone is found in the foothills, and these rocks are covered by the younger sandstone and shale of the plains, while oil pools if present may be deeply buried, there is an optimistic point of view for continued search.

D. B. Reger,* Morgantown, W. Va.—There are some small but apparently genuine seepages of very light oil in the folded Appalachian regions of West Virginia, for instance, that may have some comparisons to these Canadian occurrences. In other words, in the belt that fringes on the strongly folded and faulted Appalachians there are occasionally seepages of very light hydrocarbons in the nature of gasoline, naphtha, or something of that kind, where there are bituminous limestones interbedded in the Devonian shales. Perhaps a little attention to some of them might produce interesting results.

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* Consulting Geologist.

Mexican Oil Fields during 1930

By Valentín R. Garfias* and C. O. Isakson,* New York, N. Y.

(New York Meeting, February, 1931)

The production of petroleum in Mexico during 1930 was approximately 39,600,000 bbl., or 5,188,000 bbl. less than in 1929. The decline which has continued for the last eight years, will place Mexico in fifth or sixth rank as an oil-producing country. The production of the northern and southern fields near Tampico declined over 5,250,000 bbl., while that of the fields in the Isthmus of Tehuantepec moderately increased.

The wildcat operations which have been conducted for some years near the international border along a 290-mile belt, extending roughly 170 miles northwest and 120 miles southeast from Laredo, Texas, have so far met with little encouragement, although the oil possibilities of the region warrant the belief that commercially productive fields will be discovered eventually.

An interesting development during the year was the starting of construction of the oil pipe line from Palma Sola in the South Fields near sea level—over Sierra Madre at 8660 ft.—to Atzcapotzalco, a suburb of Mexico City at an elevation of 7350 ft. This line, about 146 miles long, has a diameter of 10 in. and an estimated daily capacity of 10,000 bbl., and with its terminal refinery at Mexico City will form a transporting and refining unit which should materially affect the distribution and marketing of refined products in the Republic.

Development

During the past year 148 wells were drilled, as compared with 214 in 1929 and 371 in 1928, the percentage of producers being 49 as against 47 in 1929. With the exception of one well in San Isidro, at the extreme southern end of the Golden Lane, the Jardín Paso Real area was the only sector of the old fields where new development could be considered as successful, all other producers brought in during the year being drilled in nearly exhausted pools to be operated as "strippers."

Northern Fields

A total of 71 wells were drilled in the northern fields, of which 22 were producers; one well in Ebano was estimated at 5000 bbl. per day, while the general average of all producers was less than 300 bbl. Results

* Foreign Department, Henry L. Doherty & Co.

in the Altamira district were as discouraging as in previous years, and of the eight wells drilled not one was commercially successful. The carbon dioxide produced by the old Quebracha wells is now used in the manufacture of dry ice, which is being utilized in the refrigerator cars of the National Railroads. Very little activity was displayed in the Cacalilao field, where only 24 wells were completed, 9 of which were producers rated at less than 300 bbl. each per day. In the Panuco field only three small producers were brought in out of 20 wells drilled.

South Fields

In the South Fields, of the 39 wells drilled, 22 were producers and of these 16 were located in the Jardín Paso Real area with 9 individually rated over 1000 bbl. per day; this portion of the Golden Lane continues with a promising outlook. Two 25-bbl. wells of a very light oil were completed in the old Tanhuijo field. A large gas well was completed out of three wells drilled in the Tierra Blanca-Chapopote-Alamo field, and two productive wells, one rated at 2500 bbl. daily out of four holes drilled in San Isidro, marked a new extension of the Dos Bocas-Alamo fault. Two wells drilled in Mecatepec in 1930 are now flowing about 20 bbl. daily each, while the discovery well in this field, drilled in 1928, with an initial daily flow of 7000 bbl. was flowing about 400 bbl. at the end of 1930. In the Furbero field, two dry holes were completed and in Poza Rica, a 25-bbl. well.

Tehuantepec Fields

In the Isthmus of Tehuantepec 28 wells were producers out of 34 wells drilled, although notwithstanding this comparatively high percentage of successful wells, the anticipated large increase in production did not materialize.

Wildcatting

Of the seven wildcat wells started during the year only four were completed, two as dry holes in Coahuila, one in Santa Monica, Nuevo Leon, and one in Camargo, Tamaulipas, which encountered shows of oil and gas. At the end of the year there were seven wildcats drilling and the equipment was being transported for three more. In Nuevo Leon three wells and one in the south fields were abandoned in 1930 at shallow depths due to mechanical difficulties. (See Fig. 1.)

A deep test near Hanover in the South Fields now drilling below 6090 ft. has shown indications of oil. In Jardín, near Alamo, another deep well is being drilled to ascertain whether or not a second oil-bearing stratum, exists below the one now producing.

FIG. 1.—OIL PIPE LINE ROUTE FROM PALMA SOLA TO MEXICO CITY (ATZCAPOTZALCO).

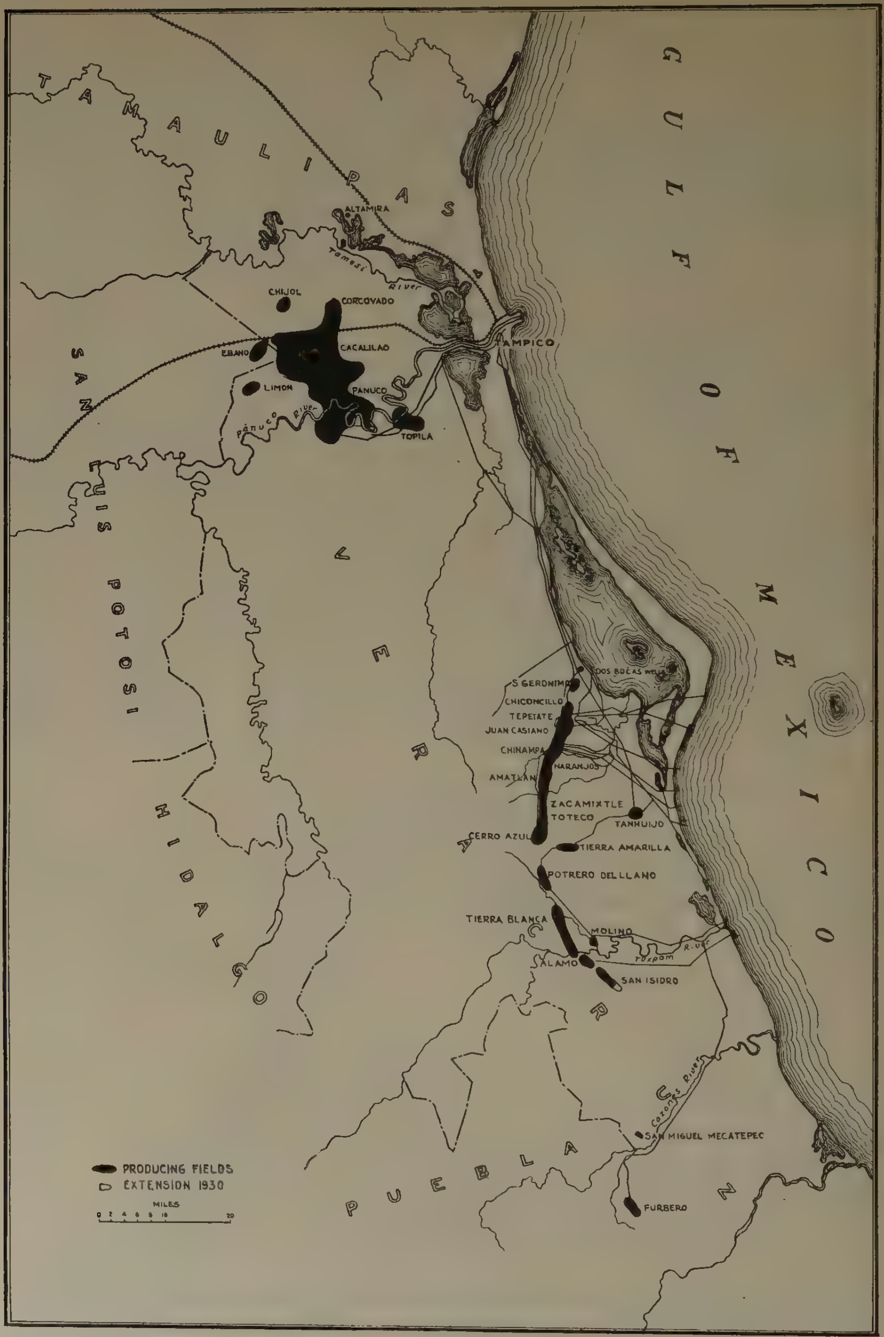

FIG. 2.—PRODUCING OIL FIELDS IN NORTHERN MEXICO.

TABLE 1.—*Wells Drilled during* 1930

	Failures	Producers	Total
Northern Fields			
Altamira	8	0	8
Corcovado	0	3	3
Salinas	1	0	1
Ebano	8	7	15
Cacalilao	15	9	24
Pánuco	17	3	20
Total	49	22	71
Southern Fields			
Tanhuijo	2	0	2
Cerro Viejo	2	0	2
Tierra Blanca-Chapopote-Alamo	2	1	3
Jardín-Paso Real	7	16	23
San Isidro	2	2	4
Mecatepec	0	2	2
Furbero	2	0	2
Pozo Rica	0	1	1
Total	17	22	39
Isthmus of Tehuantepec	6	28	34
Wildcats	4	0	4
Total	76	72	148

PRODUCTION AND STORAGE

Production in the northern fields decreased from 20,140,000 bbl. in 1929 to 16,900,000 bbl. in 1930, a decrease of about 16 per cent. The average daily production decreased from about 48,000 bbl. in January

TABLE 2.—*Oil Production by Fields*
In U. S. Barrels

	1929	1930	Decrease
Northern fields (12° Bé.)	20,142,000	16,900,000	3,242,000
Southern fields (21° Bé.)	16,283,000	13,900,000	2,383,000
Isthmus of Tehuantepec (32° Bé.)	8,263,000	9,100,000	837,000[a]
Total	44,688,000	39,900,000	4,788,000

[a] Increase.

to 44,000 bbl. in December, the daily average per well being 76.6 bbl. South Fields production for 1930 was 13,900,000 bbl., as compared with

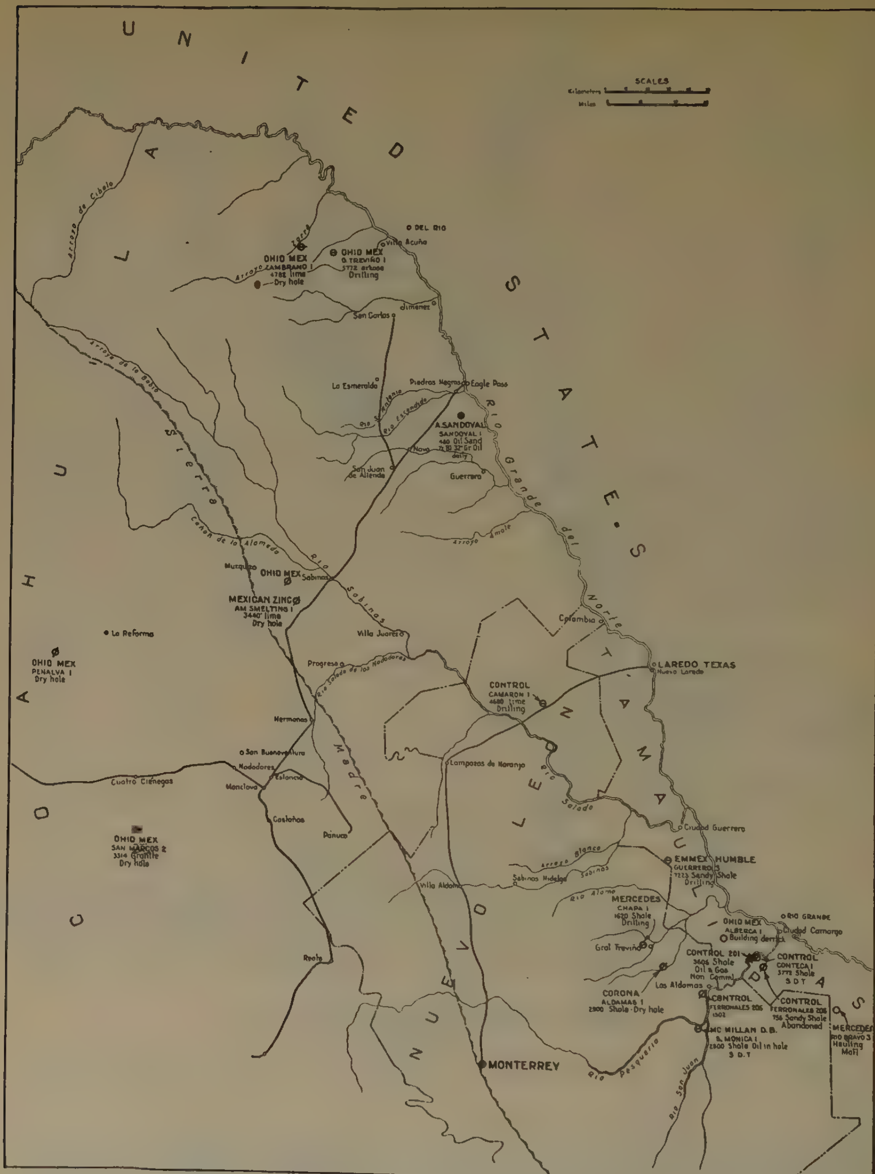

FIG. 3.—WILDCAT AREAS IN NORTHEASTERN MEXICO.

16,283,000 in 1929 or a decrease of over 14 per cent. Daily production decreased from about 42,000 bbl. in January to 33,000 bbl. in December, the daily average per well being 165.7 bbl. The fields in Tehuantepec produced 9,100,000 bbl. in 1930 as against 8,263,000 bbl. in 1929, or an

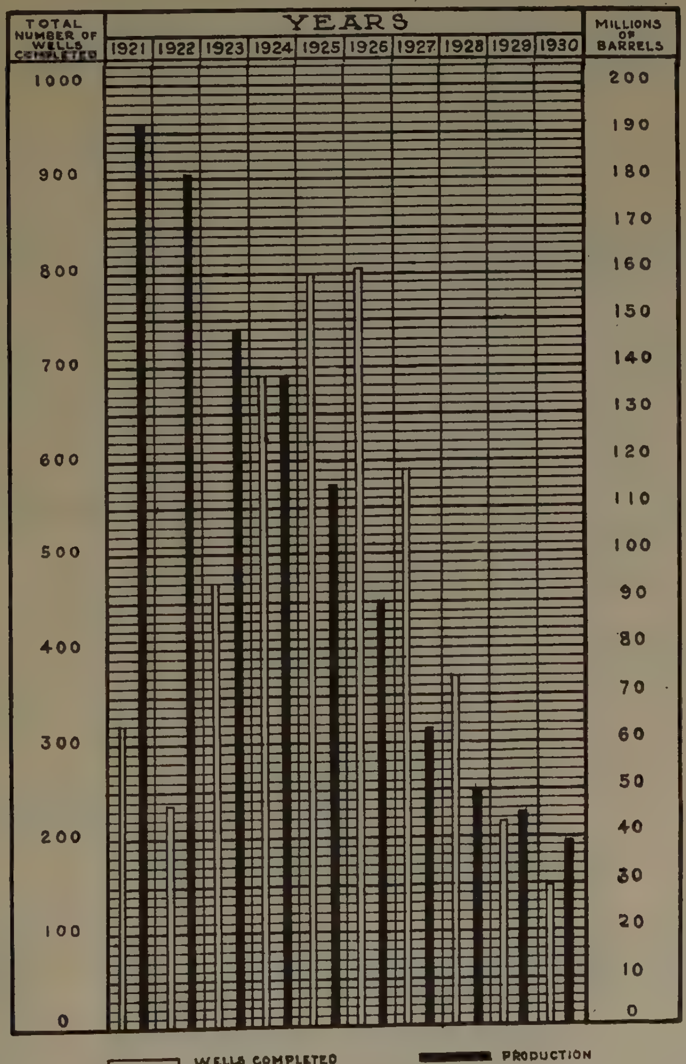

FIG. 4.—RELATION OF OIL DEVELOPMENT TO PRODUCTION IN MEXICO DURING PAST TEN YEARS.

increase of about 10 per cent.; however, the daily production decreased from 32,000 bbl. in January to 22,000 in December.

Oil in storage decreased about 1,500,000 bbl., chiefly in South Fields crude (Table 3).

TABLE 3.—*Oil in Storage*
In U. S. Barrels

	Jan. 1, 1930	Jan. 1, 1931
Heavy crude (12° Bé.)	7,896,000	7,700,000
Light crude (21° Bé.)	3,042,000	2,000,000
Topped (17° Bé.)	5,249,000	4,900,000
Refined products (including asphalts)	1,855,000	1,850,000
Total	18,042,000	16,450,000

EXPORTS

Exports aggregated practically the same as in 1929. Shipments to the United States amounted to 11,700,000 bbl., or approximately 46 per cent. of the total. Exports to Cuba, West Indies and Central and South America were approximately 5,000,000 bbl., or 20 per cent. of the total, and shipments to Europe amounted to about 3,156,000 bbl. Mexican coastwise shipments, with 3,831,000 bbl., represented about 15 per cent. of the total volume of oil exports. Exports to the United States consisted chiefly of heavy Panuco crude and fuel oil, and the greater part of shipments to other countries were distillates and refined products.

TABLE 4.—*Exports of Petroleum, by Grades in* 1930
In U. S. Barrels

Heavy crude (12° Bé.)	13,448,000	Asphalt	1,348,000
Fuel oil (17° Bé.)	5,193,000	Bunkers	1,124,000
Distillates	4,365,000		
			25,478,000

TABLE 5.—*Mexican Oil Taxes*

	Tax Rates, Dollars per U. S. Barrel		Taxes Collected by Mexican Government	
	December, 1929	December, 1930	Year	
Heavy crude (12° Bé.)	0.13712	0.12548	1920	$22,740,000
Light crude (21° Bé.)	0.22004	0.21270	1921	31,562,000
Fuel oil (17° Bé.)	0.18894	0.18073	1922	42,990,000
Gas oil	0.37605	0.36125	1923	30,268,000
Refined gasoline	0.24672	0.22789	1924	27,311,000
Crude gasoline	0.49344	0.45586	1925	21,072,000
Refined kerosene	0.15459	0.12116	1926	17,411,000
Crude kerosene	0.30909	0.24233	1927	9,512,000
Lubricants	0.28860	0.28860	1928	5,633,000
			1929	4,309,000
			1930[a]	4,000,000
				216,808,000

[a] Estimated.

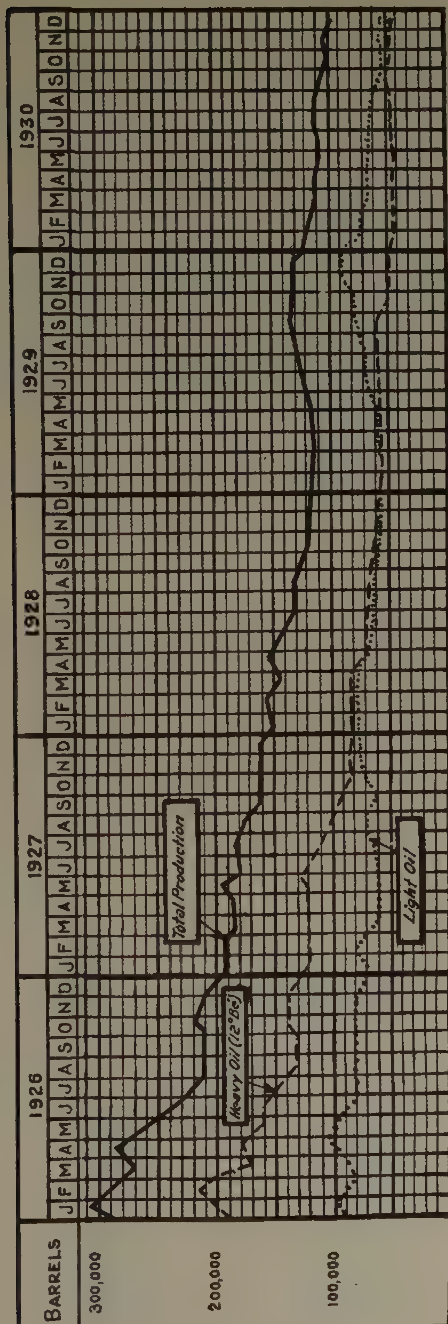

FIG. 5.—MEXICAN PRODUCTION OF OIL DURING PAST FIVE YEARS.

The taxes in effect at the end of 1930 on exported crudes and products are based on current posted bunker market prices in New York, but as the minimums established in the law for New York bunker prices have been reached, a further drop in the New York market price will probably effect no corresponding reduction in Mexican taxes.

Outlook for 1931

Judging from present indications, it is reasonable to expect that the production of the fields near Tampico will continue to decline during 1931 while that of the fields in the Isthmus of Tehauntepec will show a more even rate throughout this year. The production in 1931, therefore, should be close to 35,000,000 bbl., but should present unsettled industrial and financial conditions continue in 1931, or an oil tariff or curtailment in petroleum imports be established in the United States, the lack of demand will occasion a greater decline. The region in northeastern Mexico where wildcat operations are being carried on by several companies merits special attention as offering a possible important source of future production.

DISCUSSION

H. J. Wasson,* New York, N. Y.—Foreign oil is in general, broadly speaking, very strongly controlled. The interests owning it are quite dependable. They will resist these cuts in price, and although they are blamed in some cases for having precipitated them, such blame is wrongly placed.

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* Consulting Engineer.

Petroleum Developments in the Argentine in 1930

By Gilbert P. Moore,* New York, N. Y.

(New York Meeting, February, 1931)

Production in the Argentine in 1930 amounted to 1,415,099.7 metric tons, which converted into barrels of 42 gal., using the factor of 6.29, amounts to 8,909,773 bbl. This is a decrease of 481,613 bbl. from the 1929 production, which was 9,391,386 bbl. The production for 1930 was divided among three fields, as shown in Table 1. Table 2 covers

Table 1.—*Argentine Oil Production*, 1930, *by Fields*

	Barrels	
Comodoro Rivadavia District		
Government	4,547,670	
Railways Co	1,314,358	
Astra-Eastern	1,016,024	
Anglo-Persian	365,021	
Solano Co	24,613	
Dutch Shell	6,963	7,274,649
Neuquen District		
Government	569,245	
Standard Oil-Argentina	659,551	
Astra-Eastern	8,234	
Challaco Co. (Sol)	121,598	1,358,628
Salta District		
Government	90,576	
Standard Oil-Argentina	185,920	276,496
		8,909,773

Table 2.—*Oil Production in the Argentine*

Year	State Owned Fields, Bbl.	Privately Owned Fields, Bbl.	Total Production, Bbl.
1922	2,246,041	685,804	2,931,845
1923	2,673,076	804,524	3,477,600
1924	3,548,433	1,177,400	4,725,833
1925	4,129,454	2,335,837	6,465,291
1926	4,678,118	3,172,576	7,850,694
1927	5,175,884	3,453,763	8,629,647
1928	5,413,199	3,657,044	9,070,243
1929	5,485,956	3,905,430	9,391,386
1930	5,207,491	3,702,382	8,909,773

* Consulting Geologist.

a nine-year period and shows that the peak of production was reached in the Argentine during the year 1929. The decline in 1930 production is almost equally divided between the Government operations and those of private interests, production from the former having decreased 278,465 bbl. and production from the latter having declined 203,148 barrels.

Comodoro Rivadavia District

Government Operations.—The production of the company operated by the Government (Yacimientos Petroliferos Fiscales, usually referred to as the Y. P. F.) at Comodoro Rivadavia for the year 1930 is approximately 4,547,670 bbl. This is 529,700 bbl. less than the production for 1929, which was 5,077,370 bbl. The amount of the decline is slightly more than 10 per cent. of the 1929 production. It is reported that the decline of production from the old field is almost 20 per cent., but one-half of that is made up by production from the Y. P. F. field at Cañadon Perdido, several kilometers west of the old field. No figures have been published in support of this last statement. The decline in production per new well of the Government is illustrated in Table 3.

Table 3.—*Decline in Production in Government Wells, Comodoro Rivadavia District*

Year	Number of New Wells	Annual Production, Bbl.	Average per Well, Bbl.
1924	49	1,214,926	29,147
1925	117	1,622,191	13,838
1926	120	1,446,072	11,951
1927	121	1,154,699	9,529
1928	125	1,069,300	8,554
1929	150	1,027,850	6,919

In 1929 there was an increase of 20 per cent. in the number of wells drilled over 1928, yet production per well was decidedly less and the total did not reach the 1928 figure. This indicates that in order to maintain average production from the Comodoro Rivadavia field the Y. P. F. will be obliged to increase the number of wells completed per year very rapidly; so rapidly, in fact, that it will soon become uneconomic to attempt to maintain production at the same rate, or even impossible to do so.

In addition to producing less oil, the Y. P. F. at Comodoro is lifting more salt water with the oil each year, as is shown by Table 4.

In the figure "net" for 1929 appears 452,880 bbl., which was extracted from the new Government field at Cañadon Perdido, with which no water was lifted. Subtracting this figure from the "net" as shown for

TABLE 4.—*Occurrence of Salt Water, Comodoro Rivadavia Field*

Year	Gross Liquid, Bbl.	Net Liquid, Bbl.	Water, Bbl.	Water, Per Cent.
1927	4,985,221	4,861,133	124,088	1.97
1928	5,107,046	4,668,464	438,582	9.40
1929	6,933,599	5,077,370	1,856,229	36.80

the Comodoro field, the actual net becomes 4,624,490 bbl., and the proportion of water to the whole is approximately 40 per cent.

The Cañadon Perdido field has been in production for two years. It is near Kilometer 20 on the railway running west from Comodoro. In 1929 this field produced 452,880 bbl. of oil. The production for 1930 is not known but must be larger than for 1929, as the Y. P. F. has had five rotaries in operation there. The field has been electrified and each rotary outfit is equipped with a Hild differential drive.

During the year the Y. P. F. is said to have completed its single wildcat well at Vuelta del Senguerr. It is reported to have made 140 bbl. per day when brought in. This area is 202 km. by rail west of the Comodoro Rivadavia field and if the report is confirmed, it means a new field for southern Argentina.

The Government has begun geophysical work in this area, using both seismograph and torsion balance. No further wildcatting in this area is being planned by the Y. P. F. or others, so far as can be learned.

Royal Dutch Shell.—The Royal Dutch Shell Co. was not in active operation during 1930, as practically all operations were suspended pending receipt from the Government of a permit for the erection of a 3500-bbl. refinery in the South Basin section of the port of Buenos Aires. The 1930 production is given as 6963 bbl. while the 1929 production was 110,000 bbl. One informant says that this company has 9000 bbl. daily potential which has been shut in for some time. Unless new wells have been brought in, this figure does not check well with the 1929 total production, unless shipping facilities were restricted at that time.

During 1931 the Dutch Shell expects to resume drilling operations on a fair scale. It will operate eight strings of tools, probably rotaries. It is said to hold a block of 20,000 hectares near Kilometer 27 on the railway running west from Comodoro Rivadavia.

Anglo-Persian Operations.—The Anglo-Persian production for 1930 was 365,021 bbl. In 1929 the production was 550,000 bbl., which shows that this company's production is falling off rapidly. One writer attributes this to the fact that the Y. P. F. has drilled offsets to the Anglo-Persian acreage on all sides and by pulling its wells has cut down the Anglo-Persian production. For 1931 its production probably will be much less, since on Aug. 1, 1930 there remained only eight locations

to be drilled on the company's very small acreage. These wells are probably completed by this time.

The geologist in charge of the operations reports that already more than 1,250,000 bbl. of oil has been removed from 1 sq. km. of the concessions. This is an average of 7600 bbl. per acre over 166 acres and the field has not yet been exhausted.

This company has no other acreage in the Argentine and unless it is permitted to acquire some from the Government or can purchase acreage from some individual who still retains his concessions, probably it will be out of the Argentine in the near future.

Astra-Eastern Operations.—The Astra-Eastern is an independent company largely owned by German capital. Its production for 1930 is given as 1,016,024 bbl. The 1929 production was said to be 609,218 bbl. Production has declined steadily over three years and it is unusual that the 1930 production figures should show such an increase. Probably it is because the production of the Eastern is reported together with that of the Astra. In 1929 the combined production was 820,454 bbl., therefore in 1930 there was an increase of approximately 200,000 barrels.

Railways Company Operations.—This company is owned by the combined English Railways of Argentina and is operated to supply fuel oil for their uses. Their production for 1930 was 1,314,358 bbl., which is a decrease of about 335,000 bbl. from the 1929 figure of 1,549,286 bbl. This company has shown a steady increase in production for the three years preceding 1930 but slipped back during that year.

A deep test to 5800 ft. was completed on the company's property during 1930. No new sands were found and the well ended in a very hard formation, which was reported to be granite.

Other Operations.—About six small companies whose 1929 production totaled 137,927 bbl. are not reported in 1930. Whether these companies have shut down or their production has been bought by others and so included in the total production for 1930 is not known.

Plaza Huincul District

The 1930 production from the Plaza Huincul field was 1,358,628 bbl., an increase of 336,402 bbl. over the 1929 production of 1,022,226 bbl. This increase was divided as follows: Government, 180,190 bbl.; private companies, 155,213 bbl. There are now three distinct pools producing oil at Plaza Huincul. The Y. P. F. produces from the pool at the center of the Fiscal Reserve, the Compañia Sol and the Y. P. F. from the pool on the western edge of the Reserve, and the Standard Oil, the Y. P. F. and the Astra-Eastern from the pool east of the Reserve. The latter is known as the Dadin field. It was originally brought in by the Standard Oil Co. of Argentina.

Y. P. F. Operations.—The production from the central part of the Reserve is said to be dwindling sharply, as is also that of the field in the western part of the Reserve. The largest amount of production of the Y. P. F. is now coming from the Dadin field east of the Reserve and offsetting the Standard Oil operations. The Y. P. F. has about 40 wells in production in this area and is carrying on a moderate drilling campaign, as all line wells and offsets have been completed. The Y. P. F. had 81 wells in production during 1929 but the 1930 figure is only 72 wells.

Standard Oil Operations.—The Standard Oil Co. of Argentina S. A. operates only in the Dadin field in the Plaza Huincul district. It now has about 40 wells in production with a daily average of 2200 bbl. The oil is piped about four miles to the Challaco station, from which point it is shipped by rail to the refinery at Bahia Blanca. The Standard Oil has one torsion balance party operating in this region. It is suspected that many buried anticlines occur beneath the plains in this area. The structural geology of the region is complicated by large unconformities and buried granite hills.

Compañia Sol Operations.—The Compañia Sol operates a concession just west of the Government Reserve. It has been in operation for a number of years and now has a good many wells completed. It is said to be operating three strings of tools and shipping an average of 10,000 bbl. per month to a refinery at Bahia Blanca. This company is owned by Leopoldo Sol, who has been operating for some years in the Argentine.

Astra-Eastern Operations.—The Astra-Eastern operates acreage immediately adjoining that of the Y. P. F. and the Standard Oil in the Dadin field. It has been running one string of tools for several years but has not had much success in finding production. A recent well brought in on the edge of the property is said to have made 44 bbl. per day. All of the oil produced by this company in this area is contracted for sale to the Standard Oil of Argentina.

No company is doing any wildcatting in the Plaza Huincul district at present, although several attempts to find new pools were made in past years.

Mendoza

The Y. P. F. is the only interest in Mendoza at present. It is reported that in November of last year it brought in its first well in that district, which is said to have made 125 bbl. per hour when brought in. Conditions are not considered favorable for any large amount of production in this area.

Salta District

Production from the Salta district for 1930 shows almost a 40 per cent. increase over the production for 1929. This is due entirely to

increase in the production of the Y. P. F. operations and to the cessation of drilling operations on the part of the Standard Oil as a consequence of an injunction instituted against them by the Government. This injunction has been lifted and the Standard is now going ahead with drilling operations.

Y. P. F. Operations.—In 1929 the Y. P. F. produced 9435 bbl. of oil from their acreage known as Campo Vespuccio near the Lomitas field of the Standard Oil. In 1930 the Y. P. F. production from this field was 90,576 bbl., an increase of nearly 1000 per cent. In 1929 there were two wells on production and this number was not increased by more than one well during 1930 as far as is known.

Three wildcat wells are planned by the Y. P. F. in this area for 1931. One is located just south of the holdings of the Standard Oil and is very low on the south end of the anticline running through this area.

The other two wildcats are about 75 km. west of the Lomitas and Vespuccio field in the higher foothill country. The locations are on lands adjacent to territory once held by the Standard Oil Co. and later returned to the Government. One of the locations is on the Rio Pescado and the other on the Quebrada Solarsute. Heavy rotary equipment has been ordered for these wells and it is expected that the Y. P. F. intends to make deep tests of these wildcats.

Standard Oil Co. S. A., Argentina.—During a large part of 1930 the Standard was prevented from doing further drilling in the Lomitas field by an injunction issued by the Government. It was permitted to continue to produce from wells already in production, however, and produced slightly less than in 1929. The actual difference was only 2780 bbl., the 1930 production figure being 185,920 barrels.

In the Lomitas field near Tartagal, the Standard has completed 12 producing wells. Several drilling wells are nearing completion. They are now producing an average of 900 bbl. per day from this field. Of the total daily production, 500 bbl. are being shipped to a small refinery at Embarcacion and 400 bbl. are shipped to the company's refinery at Campana near Buenos Aires. It is reported that the Standard plans to electrify this field in the near future.

As far as can be learned, Standard has abandoned for the time being any further wildcatting in the Salta district of northern Argentina.

General Information

Petroleum activities in the Argentine have been hindered by government restriction and monopoly during 1930, as in past years. However, under the new administration which recently came into power, a more liberal policy is beginning to make itself evident. Two particular instances seem to indicate that the policy of "nationalization" of the

oil industry of the country, which had been so fervidly championed by former administrations since 1924, is being supplanted by a tendency to permit the entry of private capital and resources into the Argentine oil-producing business.

The first of these instances is the recent granting of a permit to the Royal Dutch Shell interests for the erection of a 3500-bbl. refinery in the South Basin district of the port of Buenos Aires. All of the material for the construction of this refinery has been on the ground for more than 18 months. In October, 1930, the permit for its erection was issued and it is reported that on the day following the receipt of the permit 3000 men went to work on the erection of the plant. This refinery is expected to be in operation about Jan. 1, 1932.

The second instance of a more liberal policy was the lifting of the injunction against drilling operations by the Standard Oil Co. of Argentina in the Lomitas field in the Salta district. The injunction did not prevent production from already completed wells but did stop the drilling of new wells. With the injunction lifted, Standard has gone rapidly ahead with its drilling operations.

The present administration of the Argentine has appointed a committee to study the records of the Y. P. F. over past years and determine whether or not the best production principles have been followed. Another aim of this commission is to determine the advisability of removing the administration of the Government-owned oil fields from the present Y. P. F. and placing it in the hands of a body similar to the Bureau of Mines of the U. S. A. This would remove the supervision of Government fields from politics, as appointment to office in the new bureau would be handled on a plan similar to our Civil Service, thus placing the man best qualified to handle the job in the position instead of doing so by political appointment. If this is done, the politicians will lose one of the principal patronage plums of the Government, as many positions now are filled by appointment.

The management of the Y. P. F. is again in the hands of Captain Fliess, a naval officer who had charge of the Y. P. F. in the earlier days when the only Government operation was at Comodoro Rivadavia.

It is understood that the Y. P. F. will reopen soon the purchasing office in New York, which was abandoned some time ago. Most of the equipment supply houses have established branch offices or local representatives in Buenos Aires since that time. The Y. P. F. probably expects to gain greater efficiency in purchasing by reopening the New York office.

For a time the Y. P. F. was said to be considering the laying of twin 10-in. pipe lines from Comodoro Rivadavia to Bahia Blanca. It is now understood that this will not be done because of the sharp decline in the Government production at Comodoro.

A great deal of adverse comment concerning the Government oil operations is appearing in the Argentine and foreign press. Particular attention is directed to the failure of the Y. P. F. to attain promised production figures in past years. One writer states that whereas the Y. P. F. in 1923 had promised or prophesied that in 1928 the production would reach a certain figure, the actual production for that year was about one-fourth of that promised; also that the surplus of 145,000,000 Argentine pesos, which was to be on hand at the end of 1928, according to the 1923 figures of the Y. P. F., had not resulted. Therefore, this writer argued, the Government agency was not being properly operated.

It is thought that as a result of such comments as these, together with the results of the investigation now in progress, the Government may come to the decision to cancel the reserves, which now include about 99 per cent. of all lands thought to be potentially oil bearing and may throw them open for public filing. In this event there are numerous interests that would undoubtedly like to gain a foothold in the Argentine.

It is likely that if the Government restrictions were removed and private capital permitted to enter the oil-producing industry, a petroleum law governing operations in the Argentine would be enacted. At the present time such operations as exist are carried on under a liberal interpretation of the Mining Code, which is not designed to cover the problems of control of the oil industry. A large number of decrees have been issued governing the manner of drilling, cementing and bringing in wells, but they are not properly coordinated into a workable code. The Mining Code is naturally very unwieldy and to a certain extent ambiguous, so that it is constantly subject to interpretation by the courts.

According to published reports, an agreement has been reached between the Minister of Agriculture and the gasoline importers to increase the price of gasoline by 2 centavos per liter, this increase being a tax to be turned over to the Government. This tax is expected to yield an income of 7,643,000 Argentine pesos during the first year of its operation. Consumption of gasoline is expected to increase on an average of 5 per cent. yearly, and at this rate of increase the Government will receive in 1955 the sum of 19,532,000 Argentine pesos. The purpose of this tax is to finance a road-building program calling for hard-surfaced roads connecting with two main toll roads which will join Buenos Aires to Bahia Blanca and to Cordoba. For this purpose a loan of 106,150,000 Argentine pesos has been proposed, based on the present price of gasoline. By the 2 centavo increase in price per liter the amount of this loan can be raised to 254,760,000 pesos.

This is one of the first instances of gasoline taxation for road purposes in South America, although imported gasoline pays import taxes in all countries. Oil royalties have been pledged on loans by certain countries but Argentina receives no royalty under present regulations.

The petroleum produced in the Argentine has provided about 45 per cent. of the country's requirements in the past. It is unlikely that it reached that percentage during 1930, on account of the decline in production and the increased demand for petroleum products. The Government reports that in 1929 more than 91,000 automobiles and tractors were imported into the Argentine. This number fell off at least one-third in 1930 but the increased demand for petroleum products, especially gasoline, must have caused imports of that product to increase and thus lowered the percentage of the demand furnished by domestic production.

Acknowledgments

The writer had drawn freely from the columns of the *Oil & Gas Journal* and *Petroleos y Minas.* He also wishes to acknowledge the aid received from John W. Frey, of the State Department of the United States, from Carter D. Griner, James Terry Duce and E. L. Estabrook.

DISCUSSION

G. P. Moore (written discussion).—The production figures for Argentina have been received from Mr. José M. Sobral, Director of the Bureau of Mines and Hydrology, Buenos Aires, Argentina. The figures presented by Mr. Sobral are only 20,000 bbl. less than those quoted in the author's paper, which were taken from *Petroleos y Minas.*

The Argentine Government has recently placed a tariff of 67¢ per barrel on crude oil imported into Argentina. This measure should permit the Government to increase the price of refined products to the public and thereby increase the earnings of the Y. P. F.

Considerable emphasis is being placed on recently published reports to the effect that the Argentine Government is turning over the operation of certain government-owned railways to a private company. It is thought by some that this indicates a tendency on the part of the Government to release control of certain industries and eventually may result in the oil business being placed in private hands.

It is reported that one of the major oil companies of the United States has purchased a refinery site in Buenos Aires.

Petroleum Developments in Bolivia and Chile in 1930

By Gilbert P. Moore,* New York, N. Y.

(New York Meeting, February, 1931)

Bolivia

Petroleum operations in Bolivia are still limited to those of the subsidiaries of the Standard Oil Co. of New Jersey. Development work is being carried on at Sanandita and at Bermejo and testing operations in the north. Five wells have been completed at Sanandita. Wells 1 and 2 are producers, 3 and 5, which are north of 1 and 2, are poor wells, and well 4, to the south, was dry.

In the Bermejo field, well 5 has just been completed. No information as to the production is obtainable. In the north one string was operated at each of the following locations: Machareti, Camatindi and Camiri. The well completed at Machareti during the year was a failure. The result of the others is not known.

It is reported on good authority that a pipe line will be completed in 1931 to connect the Sanandita field with the Lomitas field in the Argentine. This will place Bolivia among the ranks of the producing countries of South America for the first time. This development indicates that some arrangement has been arrived at with the Argentine Government for the importation of Bolivian oil.

During 1930 the Bolivian Government declared in effect the new Petroleum Law which had been expected for such a long time. One of the first acts of the military junta, which rose to power through a *coup d'état*, was to cancel this law, so that Bolivian oil operations are still under the old law of 1921.

One new local company was formed to exploit 1,500,000 hectares near the town of Cochabamba. The Bolivia Concessions, Ltd., which had a concession permitting the selection of 17,000,000 acres in eastern Bolivia, is reported to have failed in 1930 and is now being liquidated.

Chile

During 1930 the Chilean Government entered into a contract with an individual to explore in five distinct zones of the Republic. According to the contract, geologists must be at work there by May 1 of this year and a well must be started by the end of 1931. If the operations are

* Consulting Geologist.

successful, the Government will reimburse this individual for all of his expense and will purchase all of his oil. He is permitted to drill 10 wells after the first well which finds oil. In case of failure, all expenses are to be borne by him.

The Government has contracted five German geophysicists through a German firm in Santiago for the exploration of the Magallanes region in the South of Chile. These men are now at work there.

The Belgian company, which has a contract with the Government for the drilling of two wells near San Antonio in the southern region, has made very little progress, according to reports in the Chilean press.

The most important development in Chile is the adoption of a law creating a Government refining monopoly. This also covers hydrogenation of coal and oil. Existing concerns are permitted to continue to operate and to expand their plants. Details of the legislation have not yet been received.

Oil Development in Peru in 1930

By Oliver B. Hopkins,* Toronto, Ontario

(New York Meeting, February, 1931)

Activity in the oil industry in Peru during 1930 was confined almost entirely to the three old producing fields in the northern coastal area. In the eastern part of Peru, in the valleys of the Maranon, Ucayali and Huallaga rivers, additional geologic work was carried on, but no drilling was undertaken.

The Peruvian Government granted a concession on June 27, 1930, to W. R. Davis and associates for the building of a railroad from the west coast at Bayovar to Yurimaguas on the Huallága River. This concession contemplates the construction of 800 to 900 km. of railroad across the Andes and carries with it a grant to the concessionaire of 12,500,000 acres of land with oil and mineral rights. A similar concession was granted in 1926 but after several extensions was rescinded in July, 1929, on the grounds that the concessionaire had failed to begin work on the railroad within the time limits of the contract and its extensions.

The production in barrels from the three coastal fields of Peru has been as follows:

	1929	1930
International Petroleum Co.	10,821,117	9,766,922
Lobitos Oilfields, Ltd.	2,508,091	2,613,511
Zorritos	75,000[a]	78,000[a]
	13,404,208	12,459,060

[a] Estimated. No definite figures available.

Although not large, the Peruvian production has been steady during the past years. The reduction of approximately 8 per cent. in 1930 as compared with 1929 is the result of the world's overproduction and the attempt on the part of the International to restrict the output to conform with the available market.

International Petroleum Company

International Petroleum Co. owns the oldest producing property in Peru. The first well was drilled there in 1872. The cumulative production from the property from 1900 to 1930 inclusive has been over 92,000,000 bbl. from an area of 15,000 acres. The recovery per acre has varied

* Chief Geologist, Imperial Oil, Ltd.

from 1000 to 11,000 bbl. More than 2700 wells have been drilled on the property, of which some 1800 were producing at the end of 1930. The wells have an average depth of 1500 to 1800 ft. and an average initial production of approximately 200 bbl. The production is derived from formations of Eocene and Oligocene age. The gravity of the oil produced averages about 35° A.P.I.

The property is being operated as a unit in a modern manner. No gas is being wasted; such gas as is not required for fuel is used for repressuring. At present approximately 50 per cent. of the gas produced is being returned to the sands, with excellent results. From the plants handling the gas, some 30,000,000 gal. of casinghead is being produced annually. Of a daily production of 27,700 bbl. of oil during 1930, approximately one-half was refined in the company's plant at Talara, somewhat more than one-fourth was shipped to the Argentine and the remainder was divided between Canada, the United States and Europe. At the close of 1930 the company had a shut-in production of 40,000 barrels.

Lobitos Oilfields Limited

The two producing fields of the Lobitos Oilfields, Ltd. are near Lobitos and Cabo Blanco and represent the northern continuation of the same productive formations found on the property of the International Petroleum Co. On both properties the oil is obtained largely from formations of Eocene age.

The production from the Lobitos property has been fairly uniform for some years. Both the producing fields are on the coast. Wildcat drilling inland to the east and northward has failed to open new producing areas.

The average daily production for the past four years has increased from 6185 to 7160 bbl. The footage drilled has amounted to 100,000 to 177,000 ft. All the oil produced by the Lobitos is shipped abroad.

Oil Fields at Zorritos

For many years there has been a small oil production, from beds of Miocene age, at Zorritos, a point on the coast near the northern frontier of Peru. The production for 1928, the last year for which we have definite data, was 89,061 bbl. The estimated production for the past two years is somewhat less, amounting to 75,000 and 78,000 bbl. All the oil produced is refined locally and sold along the coast, mainly in Lima.

Petroleum Activities in Colombia during 1930

By James Terry Duce,* New York, N. Y.

(New York Meeting, February, 1931)

There were no important changes in the producing situation in Colombia in 1930, because the emergency bill passed by the Colombian Congress in 1927 is still in effect, and therefore no change has taken place in the law governing petroleum.

At the close of 1930 the Colombian Congress began to consider a new petroleum bill. This measure is an improvement on the preceding bills which had been the subject of so much debate in the Congress. However, it cannot by any means be regarded as perfect, and a number of criticisms may be justly leveled at it. The most substantial one probably is that the royalties on public lands, and the taxes on private lands, while apparently low, are deliverable at seaboard, or payable based on seaboard price at the option of the government. If the government exercises its option to take the oil at the mouth of the well, the cost of the transportation figured back into oil is also deliverable to the government. This phase of the law has the effect of making seemingly low royalties a burden on the operator. The fact that taxes on private properties are deliverable in kind is also an unusual provision for which there is no good precedent.

The pipe line provisions are also noteworthy, and the government has authority to fix rates and also to deny permits to construct pipe lines for reasons affecting national economy. There are also clauses enforcing unit operation on both public and private lands, and collecting a tax of 1 c. per 1000 ft. of gas wasted.

It remains to be seen whether this bill will be enacted, or whether it will be substantially modified. This much may be said, however, that unless it is modified, it will defeat its own purpose; *i. e.*, promotion of petroleum development in Colombia.

Company Activities

The South American Gulf Oil Co. shut down its operations during the year, and now employs only watchmen at its camps, Las Monas and El Tigre. The Standard Oil Co. of California continued operations on the Coast at Repelon and Gualapa. At the close of the year Repelon

* Consulting Geologist, The Texas Co.

No. 3 was 3025 ft. deep, Gualapa No. 2, 4468 ft. Both wells had showings of gas but nothing to indicate substantial production. Texas Petroleum Co. did only geological work, and the same may be said of Sinclair Oil Co.

There was some activity on the part of a French group, which culminated in its being granted concessions "ad referendum" by the then Minister of Industry, Sr. Montalvo. As these concessions had to be approved by Congress and the President by the close of 1930, in order to be valid, and this approval was not secured, they are now void.

The production of Tropical Oil Co. for 1930 was 20,345,916 bbl., of which approximately 391,532 bbl. were petroleum condensate. The daily average delivery for pipe line runs to seaboard was 52,291 bbl. The total volume of crude run at the Barranca Bermeja refinery during the 10 months ending Oct. 31 last, was 1,073,441 bbl., with refined products as follows: Gasoline, 251,926 bbl.; kerosene, 48,596 bbl.; gas oil, 30,374 bbl.; lubricating oil, 12,618 bbl.; cylinder oil, 2,738 bbl.; fuel oil, 711,563 bbl.

The total number of producing oil wells completed during the year was 112, with an average initial production of 697 bbl. per day. It may be said in passing that the quantity of oil produced by these wells is remarkably constant, and that because of the care the Tropical Oil Co. is taking, there is very slow decline in production. All gas not used in operations is returned to the key wells for repressuring the field. The field is now operated electrically, and in all respect is a model. The Tropical Oil Co. is continuously engaged in experimental work in the fields.

There have been no new wildcat discoveries of importance on the company's concession, with the exception of the Mugrosa well mentioned in the previous annual report.[1] One of the wells on the Colorado extension of the Infantas structure was abandoned at 6180 ft. as a dry hole. Wells Nos. 1 and 3 on the San Luis structure reached something over 5000 ft. and stopped in black shale of lower Cretaceous age without discovery of oil in commercial quantities.

Domestic Consumption

Consumption of products derived from petroleum has suffered seriously within the country on account of the financial depression, and this particularly affected the sale of fuel oil to the river boats.

Production Prospects

Regarding the future, production in Colombia will depend upon legislation and improvement in the general economic conditions affecting the oil industry.

[1] M. O'Shaughnessy: Review of Colombian Operations in 1929. *Trans.* A. I. M. E., Petr. Dev. and Tech. (1930) 583.

The present administration has shown a sincere desire to cooperate in the development of Colombian resources, and should suitable legislation be passed and settlement of controversies effected, it is probable that Colombia's production will continue to increase, and with the development of the petroleum industry will come the development of all other industries in that country.

In closing, I would like to pay my respects to the President of the Colombian Republic, His Excellency Dr. Enrique Olaya Herrera, one of the outstanding statesmen in South America, who is handling ably and with foresight a difficult economic situation.

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I wish to thank the following persons for information contributed to this report: Mr. Samuel Haskell, Texas Petroleum Co., Bogota; Mr. W. H. Heroy, Sinclair Exploration Co. of New York; Mr. R. C. Stoner, Standard Oil Co. of California; Mr. A. M. McQueen, International Petroleum Co., Canada; Captain Flanagan, Andian National Corpn., and Mr. W. Wallace, South American Gulf Oil Co., New York.

DISCUSSION

(*H. J. Wasson presiding*)

J. T. Duce.—I am not going to comment on that oil law, except to say that the three companies that have shown most interest (that is, outside producing companies, producing under contract for many years) signed a protest a couple of weeks ago on it, saying that they could not operate under the oil law as it passed the Senate. Since that protest there have been some changes in the House, but they have not been of a nature to encourage development. There have been some very good things done, but most of them are to the contrary. The bill is still under consideration. Whether we will have any development in Colombia depends entirely on what the Colombian Congress does. If the Colombian Congress passes a favorable law, probably there will be some development. However, I would not prophesy that as the result of that development there will be any substantial production of oil in Colombia for several years.

H. J. Wasson,* New York, N. Y.—Colombia is the first country we have had definitely described as being of no further menace to production for some time. I think Mr. Duce could have said the same thing about Venezuela and the same applies to each of the other countries discussed so far.[1] They are all pegged more or less at their present production. You can count on about the same production in 1931 from these countries as in 1930. Each author so far has emphasized this point.

J. E. Pogue,† New York, N. Y.—There is a clause in the Colombian oil law that I think could be commended to the Governors of Oklahoma, Texas and California—the clause that places a tax of 1¢ per 1000 cu. ft. on the natural gas wasted. If these states are anxious to increase their revenues, that would be one constructive way of doing it.

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[1] Canada and Mexico. * Consulting Engineer. † Consulting Engineer.

J. T. Duce.—The gasoline plants of the Tropical Oil Co. strip the gas and put it back in the ground, as a repressuring operation. The gasoline is added to the crude oil and run to the coast. This is an extreme measure of conservation in a country where there is not really any incentive. I think the Tropical Oil Co. deserves considerable praise for this step.

H. J. Wasson.—Is there still a substantial acreage of proved productive territory down there that has not been drilled?

O. B. Hopkins,* Toronto, Ont.—There are two very productive structures on the property. I suppose these structures have sufficient undrilled acreage to maintain the present daily production for probably five years.

F. G. Clapp,† New York, N. Y.—I do not think we should be too hard on any foreign government or on our own. After traveling in many countries, studying their oil laws and talking with politicians, oil men, promoters and others, my observations have been that every government is anxious to have American capital enter and develop its national resources whether these consist of oil, coal, gold or what not. Consequently, sooner or later a law is passed and is very likely entitled "A law to encourage oil development." For a time this may appear workable; but just as soon as capital has discovered something, the politicians become active. According to them, it is common sense to change the law so as to restrict the very capital that has been willing to take the development risks. We do not condone such a practice, but all peoples do not acknowledge American disapproval of retroactive laws. Morally, no country should change its laws after having deliberately enticed capital to enter and commence developments on account of said laws, but this is done over and over and constitutes one of the great dangers of foreign development. In almost any country that is being prospected this sort of thing is attempted sooner or later. It is logic, human nature, nationalism or Bolshevism, but it is done; and it must, therefore, be expected and discounted in any plans for foreign development.

A. A. Holland,‡ New York, N. Y.—Having spent several years in the republic of Venezuela during the early development of the oil industry there, I would like to say, in order to correct any unfavorable impression that may be held by those not familiar with that country, that I never once experienced the slightest difficulty with any member of the Venezuelan Government. I do not say that we were free from petty annoyances by local officials, but if we appealed to the authorities at Caracas matters were promptly righted. I cannot speak in any terms but the highest of Venezula for the treatment received. The laws were made so as to invite foreign capital to develop the industry there, and once there the government of President Gomez insisted that money so invested should receive every consideration.

* Chief Geologist, Imperial Oil, Ltd.

† Consulting Geologist.

‡ Consulting Petroleum Engineer.

Petroleum Development in Venezuela during 1930

By C. W. Hamilton,* New York, N. Y.

(New York Meeting, February, 1931)

In the production of crude petroleum for the year 1930 Venezuela again maintained its world rank of second only to the United States. During the latter months of the year Russia forged ahead of Venezuela in daily rate of production, and from the present outlook will probably rank second among the oil-producing countries of the world in 1931. It is now believed Venezuelan production has passed its peak.

The producing fields of the Bolivar coastal district, along the east side of Lake Maracaibo, continue to be the principal source of supply. Such fields as Lagunillas, Mene Grande and La Paz were not produced to capacity throughout 1930. During the year, three new fields entered into commercial development: The Rio Tarra field in the District of Colon, State of Zulia; the El Mene de Salto field in the District of Acosta, State of Falcon and the Quiriquire field, District of Piar, State of Monagas.

For 1930 the total crude production of Venezuela was approximately 137,424,000 bbl. as compared to 137,739,000 bbl. during 1929, or a decrease of 315,000 bbl. During the past year exports of crude from Venezuela amounted to 137,850,000 bbl. as against 130,044,000 bbl. exported during 1929. Crude oil in field storage decreased from 14,138,-000 bbl. at the beginning of 1930 to 9,600,000 bbl. as of Jan. 1, 1931—present crude stocks fill about one half the field tankage available.

Drilling operations in the producing fields declined sharply but throughout the year there was maintained a satisfactory potential reserve in the shape of proven territory and closed-in producers. Of the 2555 wells which have been completed in Venezuela, 1571 wells were in production on Jan. 1, 1931. The status of these present producing wells may be classified as follows: flowing 652, pumping 170, gas-air lift 193 and closed-in 556. The ratio of closed-in wells to producing wells declined in 1930, while the number of wells produced by artificial means increased materially. In the Bolivar coastal fields there is now observed a marked decline in gas volume and well-head pressure. Lago Petroleum Corpn. and Venezuela Gulf Oil Co. each have under construction electric plants designed to generate power for pumping wells by electricity. The first units of these plants will be placed in commission in the early spring of 1931. Venezuela Oil Concessions, Ltd. has installed a number of steam-

* Venezuela Gulf Oil Co.

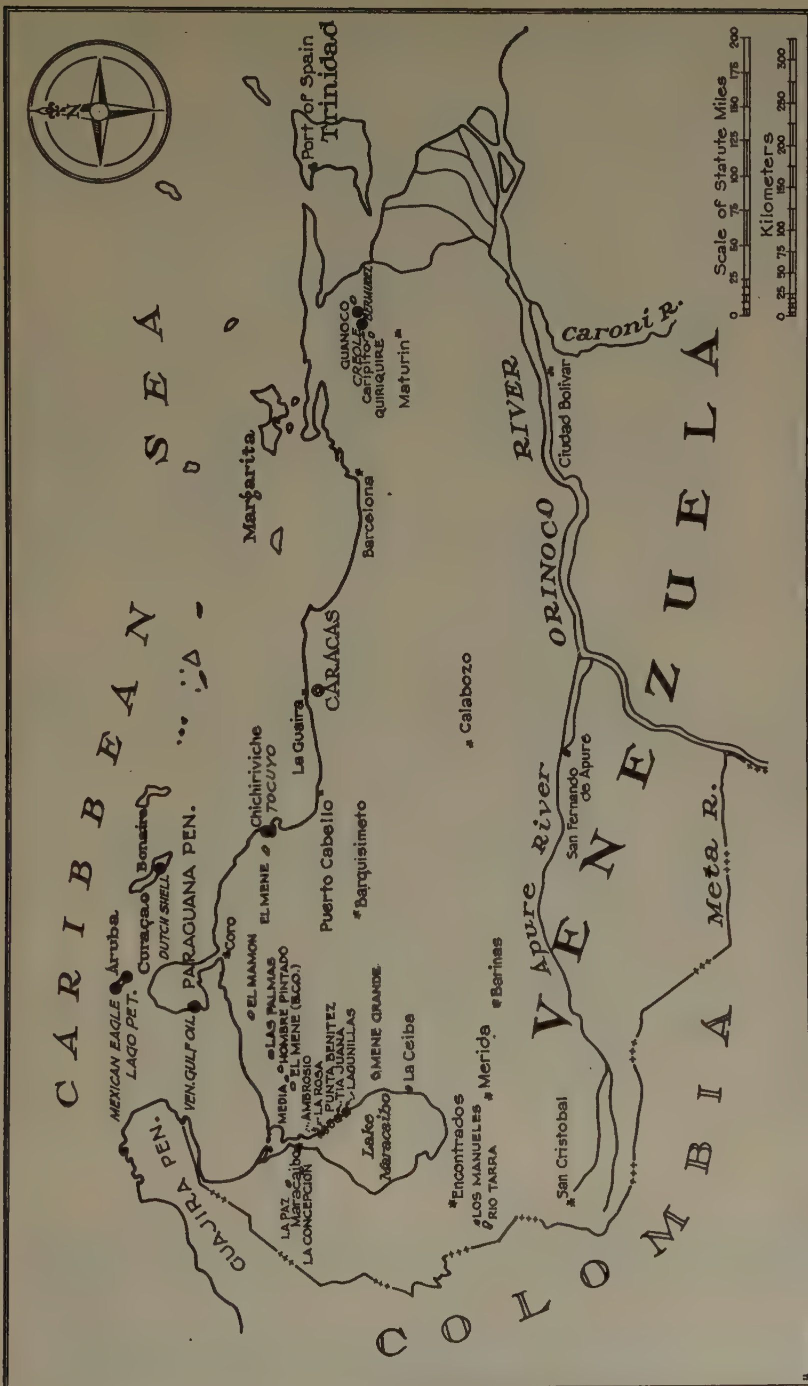

Fig. 1.—Oil fields in Venezuela.

driven central-power pumping jack stations in La Rosa, Concepcion and La Paz fields. Central power and beam pumping are being used in El Mene field by British Controlled Oilfields, Ltd. and in the Mene Grande and Colon fields by the Caribbean Petroleum Co. and The Colon Development Co., Ltd., respectively. Air-gas lift is now used in El Mene field, as also in the fields of the Bolivar coast. Where high-pressure gas is available, as in the Lagunillas area, no compressors are employed in the present gas-lift operations, though several companies are contemplating the installation of compressor units. It is believed the producing fields in the Lake Maracaibo basin area are rapidly reaching the stage of settled production.

TABLE 1.—*Petroleum Production and Exports by Years, Venezuela*
All Figures in Barrels of 42 Gallons

Year	Production	Exports	Year	Production	Exports
1917	226,000	57,000	1925	20,582,000	18,927,000
1918	367,000	144,000	1926	36,997,000	33,743,000
1919	258,000	14,000	1927	63,108,000	57,303,000
1920	526,000		1928	105,590,000	100,659,000
1921	1,498,000	998,000	1929	137,739,000	130,044,000
1922	3,394,000	1,813,000	1930	137,424,000[a]	137,850,000[a]
1923	3,741,000	3,344,000	Total to date	520,596,000	493,450,000
1924	9,146,000	8,554,000			

[a] Includes estimates for December, 1930.

Wildcat drilling toward the close of the year declined sharply, owing principally to poor results of this kind of exploration. The only new area of outstanding importance discovered in Venezuela in 1930 is located about 15 miles southeast of the Lagunillas village along the east shore of Lake Maracaibo, at a place called Pueblo Viejo.

Table 1 and Fig. 2 show the trend of Venezuela production, exports and field storage from 1917 through 1930. Table 2 summarizes production in Venezuela by fields for the years 1929 and 1930. Table 3 is a summary of wells drilled in Venezuela prior to 1929, in 1929 and 1930 and also shows a comparison of wells drilled as of the first day of 1930 and 1931.

Field Developments, Lake Maracaibo Basin

Bolivar Coast.—The Ambrosio-La Rosa-Punta Benitez-Tia Juana-Lagunillas area continues to be the source of the greater part of Venezuelan production. Drilling in this area has been reduced to a minimum. With possible small extensions to the north, the limits of the Ambrosio field have been defined and only a few proven locations remain to be drilled. On shore, in La Rosa field proper, the Venezuelán Oil Con-

cessions, Ltd. has been gradually drilling up a large block of proven acreage, the known limits of which were greatly extended during the past year.

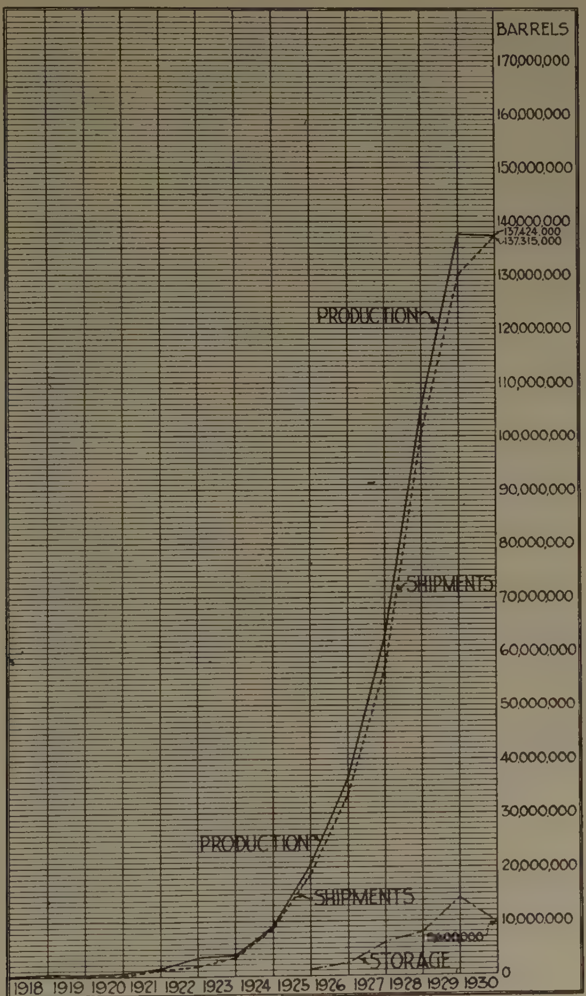

FIG. 2.—TREND OF PETROLEUM PRODUCTION, EXPORTS AND FIELD STORAGE IN VENEZUELA.

Two wells were completed in semiproven territory in the Punta Benitez area, and four exploratory wells were drilled in the Tia Juana sector. These latter wells have served to prove up additional reserves but are not being exploited at present.

In the Lagunillas field only routine drilling has been carried on. Exploratory wells drilled by the Venezuela Gulf Oil Co. outside the

TABLE 2.—*Production of Crude Oil in Venezuela by Fields*

Figures in Gross Barrels of 42 Gallons

Region and Field	1929	1930[a]	Total to Date[a]
State of Zulia, Bolivar Coast			
Ambrosio	20,957,000	8,715,000	36,301,000
La Rosa	18,420,000	19,652,000	115,945,000
Punta Benitez	604,000	229,000	3,329,000
Tia Juana	13,000	5,000	29,000
Lagunillas	78,493,000	75,647,000	245,586,000
Total Bolivar Coast	118,487,000	104,248,000	401,190,000
State of Zulia, Other Fields			
Mene Grande	15,927,000	20,804,000	88,116,000
Misoa	1,000	1,000	168,000
Rio Tarra	407,000	4,839,000	5,597,000
Los Manueles		267,000	267,000
Totumo	69,000	3,000	124,000
La Paz	82,000	350,000	1,719,000
La Concepcion	82,000	3,180,000	5,080,000
Netick	4,000	1,000	5,000
Cacuz		5,000	5,000
Amana	10,000	4,000	24,000
Total Other Fields	16,582,000	29,454,000	101,105,000
Total State of Zulia	135,069,000	133,702,000	502,295,000
State of Falcon			
El Mene—Buchivacoa	2,015,000	1,902,000	14,597,000
Hombre Pintado	39,000	26,000	91,000
Las Palmas	16,000	25,000	47,000
El Mamon	88,000	76,000	192,000
El Mene—Acosta	37,000	204,000	241,000
Total State of Falcon	2,195,000	2,233,000	15,168,000
Eastern Venezuela			
Quiriquire	49,000	1,135,000	1,227,000
Guanoco	426,000	354,000	1,779,000
Total Eastern Venezuela	475,000	1,489,000	3,006,000
Fields not Produced in 1929–30			127,000
Grand Total, Venezuela	137,739,000	137,424,000	520,596,000

[a] Includes estimate for December, 1930.

present producing limits of the field both to the north and south have proved up additional acreage. The field has been extended east on shore and west in the lake by exploratory drilling of the Venezuelan Oil Concessions, Ltd. and Lago Petroleum Corpn. The completion of Lagunita

TABLE 3.—*Summary of Wells Drilled in Venezuela*

Company	Wells Completed				Wells Drilling	
	Prior to 1929	1929	1930	Total	1/1/30	1/1/31
Apure Ven Oil Corpn						1
Belgo-Venezuelan Oil Corpn					1	[a] 2
Bermudez Co	20	2	5	27	1	1
British Controlled Oilfields, Ltd	251	30	20	301	7	[b] 9
California Petroleum Corpn			1	1		2
California Pet. Exploration Co	3		1	4	1	1
Caribbean Petroleum Co	185	35	40	260	4	[c] 8
Colon Development Co., Ltd	36	17	28	81	7	6
Creole Petroleum Corpn	48	26	32	106	6	[c] 13
Lago Petroleum Corpn	309	92	23	424	5	
Maracaibo Oil Exploration Corpn.	2			2		
New England Oil Corpn. Ltd	6			6		
Omnium Oil Development Co	2			2		
Orinoco Oil Co	1	1	1	3	1	
Paraguana Oil Corpn						1
Pet. de Minerales del Rio Pauji	1			1		
Richmond Petroleum Co	2	1	5	8	4	2
Société Française de Recherches			1	1	3	[d] 2
Tocuyo Oilfields of Venezuela, Ltd.	12	12	15	39	4	3
Union National Petroleum Co	1	1	2	4		1
Venezuela Gulf Oil Co	228	176	94	498	14	5
Venezuela Producers Inc. (Hill Bros.)	1			1		
Venezuelan Atlantic Ref. Co	2	1	1	4		
Venezuela Oil Concessions, Ltd	392	224	151	767	12	9
Venezuela Sun, Ltd	14	1		15		
Total	1516	619	420	2555	70	66

[a] One temporarily suspended.
[b] Three standing.
[c] Two suspended.
[d] One suspended.

No. 1, about 15 miles along shore southeast of Lagunillas village, as a large producer of heavy-gravity oil has probably been the most important discovery of the year. This well has opened up a new field for future development. A fair amount of light oil was secured in lower horizons in this well but, on account of mechanical difficulties encountered in drilling, these sands were plugged off and the well completed in the upper

heavy oil zone. The value of the lower light oil zone can only be determined by future drilling.

Mene Grande.—In the Mene Grande field the most important occurrence has been the finding of prolific light oil production with depth. Several wells completed in the deeper horizons have shown unusual productivity. This development has opened considerable reserves in this field. The field is entirely controlled by Caribbean Petroleum Co. and was not produced to capacity at any time during the year.

Rio Tarra.—The Rio Tarra field was placed in commercial production during the year and has maintained a steady production of about 14,000 bbl. daily. A deeper oil horizon has been found but has been exploited in only one well to date. Just north of this field, at Los Manueles, commercial production has been established but exploitation is proceeding slowly. The last well completed in this area—Los Manueles No. 4—has an initial production of 4000 bbl. daily of 32° gravity oil from about 4300 ft. and is the best well completed to date. The Colon Development Co., Ltd. completed an 8-in. pipe line 90 miles long, from the field to Lake Maracaibo, and began deliveries last February.

La Paz and La Concepcion.—La Concepcion field has been in production the entire year and a two-string drilling program has increased its production to about 14,000 bbl. per day, the maximum in the history of the field. All drilling has taken place on the northeast side of the field, where a major extension, not as yet defined, has been discovered. Production in La Paz field has been suspended the entire year and only sufficient oil produced to fulfill fuel requirements. A one-string exploratory drilling program has been maintained most of the year. These fields are entirely controlled by Venezuelan Oil Concessions, Ltd.

Totumo.—Due to the fact that the great majority of the wells completed were too small to be considered commercial producers, Creole Petroleum Corpn. has suspended drilling in the Totumo field and only sufficient production has been taken to satisfy fuel requirements.

Basin Wildcats.—Wildcatting in the western side of Lake Maracaibo (Districts of Mara, Urdaneta and Perija) has continued to be disappointing. In the District of Urdaneta, the Richmond Petroleum Co. encountered a small showing of very heavy oil in its Larrain No. 1 well, but this was not sufficiently encouraging to induce other drilling. The Société Française de Recherches au Venezuela completed its Cacuz No. 1 well in the same district at a depth of 6273 ft., as a 50-bbl. producer of 8° A.P.I. gravity oil. Another well will probably be drilled in the same vicinity but the chances of opening up a pool of major importance are considered poor. All other wildcat wells had no showing whatever. Due to the poor showing of the area, it is expected that wildcat operations west of Lake Maracaibo will be sharply curtailed for some time to come, upon the completion of wells now drilling.

Field Developments, State of Falcon

El Mene.—In the District of Buchivacoa, State of Falcon, El Mene field has been able to maintain its production by the introduction of improved production methods and an intensive drilling campaign. A small extension was opened up on the western end, but there have been no results as yet from the deep tests being drilled in the field. Four wells have been completed in the Media area, two of which rank as commercial producers and are being exploited, while a fifth is drilling. The oil from these wells is similar to that obtained in El Mene field. Due to complicated geological structure, exploration drilling in this new field is proceeding slowly.

Hombre Pintado and Las Palmas.—Drilling in the Hombre Pintado field has remained practically suspended the entire year, although the present wells are producing a small amount of oil which is being transported to the lake shore via El Mene pipe line. In the near-by Las Palmas field several good producers have been completed and the El Mene-Hombre Pintado pipe line has been extended to permit the wells in this field to be exploited. This pipe line was completed shortly before the end of the year. Other than at Media and Las Palmas, wildcat drilling in the District of Buchivacoa has been unproductive.

El Mamon.—In the District of Democracia, a few additional producers have been completed in El Mamon field, but no attempt has as yet been made to place this field on a commercial basis and drilling has been confined to wells of an exploratory character. El Mamon 1 was reworked and deepened and obtained a good showing of gas and 60° A.P.I. gravity oil from a horizon 1500 to 1800 ft. deeper than the usual producing horizon in this field.

Salto.—In the District of Acosta, the Tocuyo Oilfields, Ltd. completed a 6-in. pipe line from El Mene del Salto field to deep water at Chichiriviche and have made a few shipments of oil. The field has not as yet fully come up to expectations, though it is producing at the rate of about 1000 bbl. per day.

Wildcat drilling in the District of Silva has as yet produced nothing of interest.

Field Developments, States of Sucre, Monogas and Zamora

Guanoco.—At Guanoco, Bermudez Co. has kept in operation one string of tools only in 1930. Production has been held down to requirements. Production from this field is now averaging from 1000 to 1500 bbl. per day.

Quiriquire.—In the Quiriquire field, the Creole Petroleum Corpn. has conducted an active drilling campaign all year. A sufficient number of wells have been completed to give this field a potential production of about 10,000 bbl. daily, but at present the field is actually producing

7500 bbl. per day. The oil is shipped via pipe line to Caripito on the San Juan River and there transferred to tankers. The field has not as yet been closely defined. So far about 2500 acres have been definitely proved for production.

Zamora.—The Apure Venezuela Petroleum Corpn. is drilling a wildcat in the District of Barinas, State of Zamora. This well has been closed down because of mechanical difficulties, at 5190 ft. No oil or gas shows of interest have been encountered to date.

General Comments

Table 3 lists the wells completed in 1929 and 1930 and wells drilling as of Jan. 1, 1930 and Jan. 1, 1931, by companies. During 1929 there were 619 wells completed in Venezuela, while only 420 were completed in 1930, a decrease of approximately 33 per cent.; 70 wells were listed as drilling as of Jan. 1, 1930, while 66 wells were listed as drilling on Jan. 1, 1931. However, of the 66 strings listed in operation on the first of this year, 9 have been temporarily suspended or standing for some months, which in reality leaves only 57 strings actually in operation in the entire country. Of these 57 strings, by far the major portion are being used in wildcat and semiwildcat territory. The number used in the major producing fields has decreased over 25 per cent. from those used in the same fields as of Jan. 1, 1930.

Table 4 lists the lake tanker fleets which have operated in the Maracaibo Lake basin during the year 1930. At the end of the year four of the ships of the Caribbean Petroleum Co. were transferred to other parts of the world. The Lago Petroleum Corpn. has had some of its smaller ships laid up, while the fleet of the Venezuela Gulf Oil Co. fleet is operating on a reduced schedule. Temporarily one ship of the Creole Petroleum Corpn. is stationed in eastern Venezuela to assist in loading deep-sea tankers from the Quiriquire field.

1931 Forecast

Provided the present rate of production continues throughout the year without marked change, the total crude production in Venezuela for 1931 will be substantially less than in 1930. It is anticipated that drilling completions will abruptly decline both in proven territory and exploratory. Field stocks will probably remain about the same throughout the year. As well as can now be determined, 1931 exports may be expected to decline as much as 10 per cent. from the 1930 record.

During the ensuing year pumping with electric power will be started. Power can be delivered from two central plants for a linear distance of about 40 miles along the Bolivar coast of Lake Maracaibo. This development is unique in that wells to be so pumped are located in Lake Mara-

TABLE 4.—*Maracaibo Lake Tanker Fleets*, 1930

Company	Number and Capacity of Tankers					Total ships
	21,000 bbl.	17,000 bbl.	14,000 bbl.	12,000 bbl.	Smaller than 7000 bbl.	
Caribbean Petroleum Co		29	3	1	2	35
Creole Petroleum Corpn	3					3
Lago Petroleum Corpn	3	17			2	22
Mexican Eagle Oil Co		3				3
Venezuela Gulf Oil Co	3	8	4			15
Total	9	57	7	1	4	78

caibo; in fact, one of the companies undertaking this kind of installation has located its entire transmission and distribution system over water.

DISCUSSION

(*H. J. Wasson presiding*)

H. J. WASSON,* New York, N. Y.—In the past, Venezuela has always elicited a great deal of discussion—sometimes heated. We have heard the great "wave of foreign oil" mentioned several times. It may be noted that the production is the same as it was in 1929, within less than 1 per cent. Mr. Duce may have led one to believe that there was not quite a proper degree of curtailment, or at least I seemed to gather that impression.[1] There are two ways of curtailing. Imagine two men, each with 100 acres of territory. One man drills 100 wells on it; the other man drills one well. The man with 100 wells produces 1 per cent. of what his 100 wells would produce, so he is, of course, curtailing. The other man drills only one well and produces it perhaps 80 or 75 per cent., and he is said not to be curtailing, in some circles.

J. T. DUCE,† New York, N. Y.—I tried to be strictly neutral. I said that the production has been regulated by not drilling, but I also said there had not been any sign of this 20 per cent. reduction that the companies talk about.

H. J. WASSON.—That is exactly to what I refer. That might create a misleading impression on one who was not thoroughly familiar with the facts. Another way of looking at it (it is in Mr. Hamilton's report) is that there are something like 50 wells in Venezuela in operation. That represents the drilling activity of the second oil-producing country in the world. I think somebody said a few minutes ago that he saw something like 300 new wells from a hilltop in Gregg County while on a brief visit there, and more to come. Yet we will hear about much proration in Gregg County, I am sure. I am just mildly accusing you of not giving us the whole story.

J. T. DUCE.—It is rather more easy to regulate production in Venezuela, where there are three companies holding the concessions they have under the contracts than in Gregg County under the laws of the United States. That is a legal question.

* Consulting Engineer.

[1] Mr. Duce presented the paper for the author.

† Consulting Geologist, The Texas Co.

Trinidad Oil Fields in 1930

By William J. Millard,* Pittsburgh, Pa.

(New York Meeting, February, 1931)

The Island of Trinidad has much the same geological history as the continent of South America. There are present in this area Cretaceous, Tertiary and Quaternary rocks, which were deposited in a basin covering eastern Venezuela and Trinidad, very much as rocks of the same age were

Fig. 1.

deposited in the Maracaibo Basin in western Venezuela. Along the north coast there are metamorphosed and semimetamorphosed Cretaceous rocks which are found as semicrystalline limestone, schists and quartzites, etc. Both the Cretaceous and Tertiary rocks are petroliferous and are responsible for the production of oil in Trinidad and eastern Venezuela. The geological column in the oil-bearing region of Trinidad is shown below.

* Huntley & Huntley.

Table 1.—*Geological Column in Oil-bearing Region of Trinidad*

Formation	Age	Thickness, Ft.	Description
La Brea or Upper Moruga	Upper Miocene	300 to 7000	Clays and sands sometimes ferruginous, porcellanites, lignite and rare Ostrea beds.
Morne L'Enfer	Upper Middle Miocene	650	Thick sands, clays and sandy clays at times extremely petroliferous. Give rise to the Pitch Lake at Brighton.
Forest Clay	Lower Middle Miocene	0 to 130	Greenish clay contains first appearance or cyclamina cancellata. Changes laterally to oil sands at times.
Stollmeyer Zones	Lower Middle Miocene	350	Producing oil sands, clays and sandy clays.
Intermediate Zone	Lower Middle Miocene	650	Producing oil sands, clays and sandy clays.
Cruse Zone	Lower Middle Miocene	620	Producing oil sands, clays and sandy clays.
134–11A Zone	Lower Middle Miocene	420	Producing oil sands, clays and sandy clays.
35 Zone	Lower Miocene (?)	800	Oil sands, clays and sandy clays.
Upper St. Croix	Lower Miocene	500 (?)	Oil sands, clays and sandy clays.
Lower St. Croix	Oligocene	500 (?)	Oil sands, shale, sandy shale and lenses of limestone.
	Eocene	1000 (?)	Oil sands, shale, sandy shale and limestones. (?)
Guanoco Shale	Upper Cretaceous	3000	Black petroliferous shale. Oil sands near the top.
Laventille Limestone	Lower Middle Cretaceous	800	Hard blue gray limestones containing deformed rudistes. Oil bearing at times.

Shown compactly, it is as follows:

		Remarks
Upper Miocene	300 to 7000	Absent on crest of folds
Middle Miocene	3100	Oil producing
Lower Miocene	1300	Oil bearing
Oligocene	500	Oil bearing
Eocene	1000	Oil bearing
Cretaceous	3000	Oil bearing

The Tertiary therefore ranges from 5900 to 12,600 ft., of which 5600 ft. contains oil sands. The bulk of the oil at present is derived from the first 3100 ft. of oil-bearing strata.

The Trinidad metamorphosed Cretaceous sediments are found in the northern part of the island and form the Northern Range. Another

strong range through the center of the island is called the Central Range and contains a few exposures of Cretaceous sediments. At two small and isolated spots in the Southern Range the Cretaceous again appears.

Between the Northern and Central ranges the area is covered by Quaternary, Pliocene and Upper Miocene rocks. Between the Central and Southern ranges is a basin consisting largely of Miocene strata. Eocene, Oligocene and Miocene sediments are found in both the Central and Southern ranges.

Structure

The sediments have been strongly folded, resulting in numerous parallel anticlinal folds running about N. 65°E. Folding probably commenced at the end of Cretaceous time and went on in the Tertiary to at least the end of Miocene time. This gradual movement was accompanied by various depressions, finally resulting in the forming of two powerful folds, the Northern and Central ranges, accompanied by considerable lesser and parallel folding. Thus were formed several persistent anticlinal folds which today form the producing oil fields of Trinidad. The effect of this deformation and folding may be traced for several hundred miles into Venezuela.

Oil Production

The pools named in Table 2 are being operated. The average depth of drilling is 1600 ft. Many wells have yielded large amounts of oil at 500 and 600 ft. The gravity of the oil varies from 14° to 46° Bé. Single wells produce from 30,000 to 500,000 bbl. of oil. The oil per acre actually produced in the oil fields runs from 4,000 to 18,000 bbl. per acre, while the total ultimate production probably will run from 5000 to 20,000 bbl. per acre. The production from 1908 to date is given in Table 3.

Table 2.—*Oil Pools of Trinidad*

Field	Structure	Date First Drilled
Guayaguayare	Anticline	1902
Point Fortin	Open anticline	1907
Brighton and Vessigny	Anticlines	1908
Barrackpore	Thrust fault	1910
Palo Seco	Asymmetric anticline	1910
Cedros	Anticline with horst	1910
Lot One—Parrylands	Anticline	1911
West Fyzabad	Anticline	1913
Los Bajos	Nose	1915
Apex-San Francique	Open anticline	1919
Tabaquite	Thrust fault	1922

TABLE 3.—*Production*, 1908–1930

Year	Production, Bbl.	Year	Production, Bbl.
1908	169	1921	2,354,159
1909–10 (15 months)	10,372	1922	2,444,751
1910–11 (12 months)	125,112	1923	3,050,872
1911–12	285,307	1924	4,284,000
1912–13	503,616	1925	4,387,000
1913–14	643,316	1926	5,278,000
1914–15	1,050,112	1927	5,200,000
1915 (9 months)	671,124	1928	7,750,000
1916	927,877	1929	8,715,652
1917	1,602,311	1930	9,500,000 (Estimated)
1918	2,082,068		
1919	1,841,046	Total	64,789,891
1920	2,083,027		

The number of wells estimated to have produced this oil is probably divided between the major companies as follows:

Company	Field	Number of Wells
Trinidad Leaseholds	Barrackpore	80
Trinidad Leaseholds	Forest Reserve	275
Apex	Apex	130
General Asphalt Co.	Brighton-Lot One-Vessigny	70
United British	Point Fortin-Parrylands	175
Oropouche (Trinidad)	Fyzabad Nose	40
British Controlled	Oropouche Lagoon & Palo Seco	40
Trinidad Oil Fields	Fyzabad, San Francique & Palo Seco	35
Kern River	Guapo	50
Total		895

Roughly, there may be estimated a total production of 65,000,000 bbl. of oil from a total of about 900 wells. This gives an average production per well of 70,000 bbl. Thus it may be seen that production would run 7000 bbl. per acre if only one well per 10 acres had been drilled. In reality there have been approximately 2 wells drilled to every 10 acres, which would put the average recovered production at about 14,000 bbl. per acre.

Oil Sands

The oil sands in Trinidad are prolific and numerous. Owing to faults and actual outcrops of oil sand, oil and gas seeps are found over much of the southern half of the island. More oil sands exist in the southern and western part than in the eastern part. The bulk of the production comes from sands of Miocene age. Oligocene, Eocene and Cretaceous oil sands exist in depth but have not yet been tested.

A change from southwest to northeast from sandy strata to sediments containing more clay indicates that the source of sedimentation was to

the southwest. Furthermore, underground maps of the oil sands indicate large lenses of sands running southeast and northwest, which may indicate shore line and deltaic deposits. It is believed, therefore, that in eastern Venezuela much thicker sands will be encountered, as that area is closer to the source of the sands.

The oil sands vary from 10 to 50 ft. in thickness. Thick zones of alternating thin sands and clays or shales sometimes form the pay. In this case liners from 200 to 600 ft. long of screened or perforated pipe are used.

Water Sands

Salt-water sands are present even on the crests of anticlinal structure. They are separate and distinct from oil sands. Edge water and bottom water are not known except where the water has been let into oil sands by the failure to take proper precautions in drilling. There are some instances in which salt water may have entered where light-gravity oil sands outcrop in the sea bottom. The salt-water sands are shut out by using a water string of casing.

Drilling Methods

All drilling is done by the rotary drill, as the rocks are soft. All casing used as water strings must be cemented, and the cement allowed to set from 10 to 12 days. On all wells it is advisable to core before setting a string of casing, so as to make certain of being through the water zone and getting as close to the oil sand as possible.

When drilling into a high-pressure sand an oil string consisting of part or all flush-joint pipe is used. A stuffing box is used in the well so that the drill may go through the oil sand and not have the hole emptied of mud by blowing out. A blow-out preventer is also used as an extra precaution. On the bottom of the oil string are several joints of screened pipe or perforated pipe. Circulation to the bit is maintained by the use of a 2-in. "wash" pipe extending through the perforated pipe and held by cast-iron wash rings so that the drilling fluid must pass to the bit. On the bottom of the perforated or screened pipe is the drill collar, back-pressure valve and bit.

On completion, the wash rings are broken, wash pipe pulled with an overshot or a spear and the oil brought in through the screened pipe. A centrifuge should be kept on the well to determine the amount of sand coming out, since only a small amount of flourlike sand may be allowed to get out. If perforated pipe is used, the well should be permitted to flow on the outside of the oil string for some time before bringing it in through the perforations. A cavity is formed underground and in caving becomes

filled like a shrinkage stope in mining. If no cavity is allowed to form, shale or clay will get between the perforated pipe and the oil sand and kill the production.

The average well should be completed in 45 days. Many wells are completed in less than one month. Drilling should not exceed $10 per foot. Wells of shallow depth necessarily cost less per foot than do deep wells. Where the producing horizons are known, only one water string need be set. About 200 or 300 ft. of 15½ or 12½-in. conductor cemented is used with 11, 10 or 8¼ in. as a water string. If the pressure permits, a liner with lead seal may be set. The liberal use of the core barrel is recommended.

Lifting

About one-third of a large well's total production will flow. The remainder must be pumped at a cost which can be made low by efficient methods and organization. The wells will produce for about 20 years. Many wells are already over 15 years old.

Leases

The land is divided into large and small estates. On single estates of several thousand acres, the rental paid is from $5 to $15 per acre. Much of the coolie land in 5 or 10-acre tracts has a more or less established price of $28 per acre. On small leases there is usually a clause to the effect that if oil is found the lease is to be purchased at a cost ranging from $300 to $500 per acre. No royalty is paid on such leases.

Often the large estates insist on a 10 per cent. royalty. Option to purchase large estates may be obtained whereby the price will range from $250 up to $500 per acre. Sometimes the owner asks for 2.5 or 3 per cent. royalty after purchase. All leases contain a schedule of prices for damages due to growing crops. Cocoa trees, coconut palms, banana roots, etc. must be paid for if destroyed by clearing a drilling site, etc. These prices range from a few cents up to a few dollars.

Reserves

The reserves on present drilled and closed in acreage probably amount to about 80,000,000 bbl. of oil. Other areas not yet drilled may yield about 177,000,000 bbl. of Tertiary oil. This undrilled and unleased acreage is roughly 30,000 acres. There are also about 78,000 acres of unleased land which may yield Cretaceous oil, of which the possible reserve is estimated at 810,000,000 bbl. Thus the total possible reserves of oil amount to 1,067,000,000 bbl. This is a large amount of oil for an area about the size of one of our Oklahoma counties.

DISCUSSION

C. P. Collins,* McAlester, Okla. (written discussion).—In a brief way Mr. Millard has very satisfactorily brought out the significant facts regarding the geologic history, stratigraphy and petroleum production history of the Island of Trinidad.

I believe that the Tertiary system as a whole contributed and gave rise to the Pitch Lake, rather than the Morne L'Enfer horizon, as indicated in Table 1.

The present practice of coring a well continuously after setting the first water string has revealed an average thickness of over 5000 ft. of strata in the lower half of the Miocene, in the Lot Four-Parry Lands district, as compared to about 3300 ft. as described by Mr. Millard. This section is based upon foraminiferal evidence from well logs in this area.

During 1929 and 1930 it was the general practice among the major operators to core a well continuously after setting the water string, with the aid of barites ($BaSO_4$)-laden mud. While this method was necessarily more costly, its advantages were great enough to be warranted. Owing to the lenticularity of the oil and water sands, as mentioned by Mr. Millard, as well as the thin shale bedding which often separates prolific oil and water sands, a true and reliable sample of the strata as revealed by the core is most important from a production viewpoint. After a well has been cored in this manner, additional water strings can be run if necessary and the production string with the exact amount and size of screen or perforated pipe can be set. After flow connections, traps and other necessary lines are connected, the barites-laden mud is washed from the well and the well brought into production. This method has resulted in the bringing in of many wells from sands which heretofore were passed up as nonproducers under the old method.

The vast information as revealed by the core barrel during the past two years in the Trinidad oil fields might have an important bearing on the reserves as estimated by Mr. Millard.

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* Consulting Geologist.

Russian Oil Fields in 1929–1930

By Basil B. Zavoico,* Tulsa, Okla.

(New York Meeting, February, 1931)

The oil industry in the Soviet Union closed the 1929–1930 operating year fulfilling its assigned program. During this period of time, however, no basic improvements were noted within the industry. A careful study of the conditions indicates that disorganization in most branches increased continually; that supply and transportation problems are approaching a state of breakdown; that labor problems become increasingly difficult and that the estimates for 1931–1933 period are too large.

The production of all Russian fields increased by 27,200,000 bbl., as compared with the 1928–1929 operating year, while the next year's program anticipates a further increase of 46,000,000 bbl., and the 1933 plans call for an amazing total of 330,000,000 bbl., or over 150 per cent. more than the production of the operating year that has just closed.

Table 1 shows petroleum production in Russia by individual areas and fields from 1916, and furnishes estimates for the three coming years, which constitute the balance of the Five-year plan.

A brief analysis of Table 1 will show that the Soviet Planning Commission anticipates that the fully developed fields of the Apsheron-Baku will double their production by 1933, as compared with 1929–1930, and that the old Grozny fields, which are already showing a tendency to decline, will increase their output from 44,110,000 bbl. in 1929–1930 to 68,000,000 bbl. in 1933. Furthermore, in 1933 new fields are slated to produce not less than 100,000,000 bbl., a figure which even under most favorable conditions in Russia would be hard to achieve. Of course, Russia could develop such production, because the country is not lacking in the prospective reserves, but the transportation in the country today (as in the past) is in such poor shape that neither the supply of a gigantic oil industry nor the movement of its products is within the realm of possibility. Table 1 shows the future estimated crude oil production as required by the Five-year plan, and also as reasonably estimated by the author, taking into account natural declines in old fields, slow development of new areas and the deficiency of the transport. While in the 1929–1930 operating year only two major fields underproduced (Surakany and Maikop) and the plan was fulfilled to the extent of 97.4 per cent., the production of the last three months of 1930 ("Shock Quarter") indicated

* Consulting Geologist.

a general failure in Bibi-Eibat, Surakany, Balakany-Ramani, Binagadi, Kara-Choukour and Maikop fields, resulting in an underproduction of fully 8 per cent.

Baku-Azneft

The oil fields of the Apsheron Peninsula continued to be of major importance in Russia. Their average production increased from 170,000 bbl. per day in 1928–1929, to 202,000 bbl. in 1929–1930, while production in November of 1930 reached 228,000 bbl. It is becoming quite apparent that even to maintain such production a very active continuous drilling campaign is necessary, which is bound to reduce the land reserves correspondingly fast. At this time, in the older proven fields of the Baku area, the undrilled reserves are very small; in the Surakany field there are some 170 undrilled acres, now occupied by a village, which is in the process of being moved away, and in the Bibi-Eibat Bay Extension some 300 acres additional may be considered as proven, though most of this acreage will not be available for drilling for another two years, until the filling-in of the bay is completed, also in Kara-Choukour field there may be some 500 acres available for development in the near future. Incidentally the very conservative development plans of the Soviet management state that not less than 500 wells will be drilled in the next two years on the Surakany's village 170 àcres, or an average of one well to less than 0.34 acres.[1]

Surakany, the main producing field of Baku area, fell some 13 per cent. behind the plan during the 1929–1930 operating year, and the November, 1930, figures indicate similar underproduction. The Surakany field has been rapidly exploited in the last three years, with the result that even the most recently developed deep horizons, V and VI, have been considerably depleted and flooded. In particular, horizon V, which furnishes over 50 per cent. of the total Surakany production, shows a decline of the initial production of its new wells from 36,000 bbl. per month in 1926–1927, to 13,000 bbl. per month in 1929–1930; and the average per month production for all wells from horizon V declined from 26,000 bbl. in 1926–1927 to but 10,000 bbl. in 1929–1930, the decline in the last six months being more than 50 per cent. Also, the much hoped for VIth horizon has been badly mismanaged so far, and eight completions out of the 12 showed water. The southeast extension of Surakany, the Kara-Choukour sector, is continually falling behind planned figures, even the reduced ones, producing but one-third of its assignments.

During the month of November, 1930, Baku fields did show very serious underproduction, producing but 91.2 per cent. of the plan. Individually the Balakany-Ramani underproduced 4.7 per cent.; the

[1] *Azerbeidjanskoie Neft Khosiastvo* (1930) No. 11, 153; *Za Neft Piatiletka* (1930) No. 16, 20.

TABLE 1.—*Russian Petroleum Production by Fields*

Millions of Barrels

	1916	1922–23	1927–28	1928–29	1929–30	1931[a] Estimated		1932 Estimated		1933 Estimated	
						Soviet	Author[b]	Soviet	Author[b]	Soviet	Author[b]
Baku	55.81	25.30	54.15	62.10	73.60	98.00	80.00	120.00	90.00	146.00	100.00
North Caucasus	12.73	10.90	26.50	32.40							
		undivided									
Old Grozny (Old and New)					44.11	58.00	55.00	61.50	50.00	68.00	50.00
Maikop					3.00	8.80	6.00	17.00	15.00	28.40	30.00
New Grozny (Benoi)						1.10		5.60	10.00	14.50	20.00
Kuban								2.90	3.00	14.50	15.00
Others										7.30	0.00
Emba	1.82	0.97	1.82	1.86	2.46	2.90	2.90	7.50	3.00	20.30	5.00
Saghalien		none		0.23	0.51	1.90	1.90		3.00		5.00
Ural		none			0.04	negligible					
Turkestan	0.44		0.26	0.26	0.28	0.90	0.90	1.85	3.00	3.60	5.00
Balance (?)						8.40	0.00	23.65	3.00	27.40	5.00
Total	72.80	37.17	82.60	96.80	124.00	180.00	146.70	240.00	180.00	330.00	235.00

[a] The Soviet Government has discontinued the former uneven operating year policy and is substituting the regular calendar year. The months of October, November and December, 1930, have been classified as a special "Shock Quarter" in which it was planned either to catch up with the Five-year plan or to create reserves for the coming three years.

[b] Reasonable estimates by the author.

Surakany, 12.7 per cent.; Bibi-Eibat, 8.8 per cent.; Binagady, 9 per cent. and the Kara-Choukour, 64 per cent. The great significance of this underproduction is due not to the current stabilized production but to the fact that all the fields of the Baku area are near the maximum of their output, and will begin to decline in the very near future, regardless of how many new wells may be drilled. A very significant factor is that the naturally flowing wells in all Baku fields have reduced their proportional production of the total from 28.8 per cent. in 1928–1929 to 25.2 per cent. in 1929–1930, though the total footage drilled increased by fully 30 per cent. during this same period of time. It is also probable that the area occupied by the Surakany village will prove to be most disappointing to the Soviet planning agencies, as it is near the center of the field and has been unquestionably affected by reduced gas pressure, by drainage and by the water-flooding.

While the above indicated localized factors may have caused the current underproduction, the underlying reason for it is other than these. During the past 40 years the 12 square miles which compose all fields of Baku district have been developed extremely slowly. The wells took as long as one year to complete to the depth of 2000 ft. Few wells were on the air-gas lift, the majority of nonflowing wells being produced with the ordinary bailing equipment. Since the nationalization of fields, rotary rigs have been introduced and at this time all drilling is done by fast American tools; also deep pumping units have replaced bailing. Therefore, relatively speaking, crude oil is now being produced much faster than before; arbitrarily, at least six times as fast. However at no time has total production greatly exceeded that of 1916, although in the past operating year a total of 1,320,000 ft. was drilled in the Baku area, as compared with the prewar maximum of 530,000 ft. In other words, a 160-per cent. increase in drilling resulted in a 25 per cent. increase of production. The Baku fields at this time evidently are being overdrilled in order to secure maximum flush production. To each horizon the wells average one to 3.5 acres in the newly developed extensions, whereas one well to 10 or 15 acres would be entirely sufficient under a single ownership operation.

No new fields of any importance have been developed by the Azneft in the past 10 years. Small wells have been discovered at various points of the Apsheron Peninsula and also south of it, in the Saliani steppes, but none are commercially productive at this time. Because of this failure, the future new developments stress drilling to deeper formations in the older fields; more particularly to the Miocene and Oligocene formations. This development is desired because all surface equipment, shops, roads and pipe lines will immediately become available to new reserves. The Binagadi field, in which only the lowest section of the Pliocene "oil measures" is present, should be explored

first in deeper formations, since in that field they will be found at much shallower depths than to the East, in the Balakany-Surakany group.

In all probability both the Miocene and Oligocene sections will show commercial accumulations of oil, though the great depth to them in most of the fields, below 5000 ft., will delay the development considerably, even after the discovery.

The speed of drilling in Baku fields continues quite unsatisfactory. The average per month per rig footage in 1929–1930 was 320 ft., against 288 ft. in 1928–1929. During 1931 it is planned to increase the footage to 545 ft. per rig per month, and in 1933 to 1000 ft. The plans will not be fulfilled at all unless the whole system of supply is reorganized, as indicated elsewhere in this paper.

North Caucasus-Grozny-Grozneft

The two Grozny fields, old and new, continued their routine development. Because of underproduction in Baku and Maikop fields, the New Grozny field was forced to its limit, increasing the gusher production of Grozny area from 74 per cent. of the total in 1928–1929 to 80 per cent. in 1929–1930. Such increase in an old field resulted immediately in the flooding of many wells, and though the management anticipated having 57 producing gushers at the end of the 1929–1930 operating year, it had left only 43; and though it anticipated 12 gushers to stop flowing during the year, 22 actually had to be transferred to pumping or gas-lift. That the situation is realized by the local engineers can be seen from the reduction of the naturally flowing oil to 67.3 per cent. of the total in 1931. Interestingly enough, however, the production of the two old fields (old and new) in Grozny, from formations developed at this time, is expected to increase till 1933, when these two fields are assigned 68,000,000 bbl., against 44,110,000 bbl. produced in the past year. (The reasonable estimates for 1931, 1932 and 1933 given in Table 1 for these two fields anticipate that at least some production will be obtained from the lower formations, as yet not tested.)

The close of 1930 was notable in Grozny by the first really important wildcat discovery in the past 15 years. A test started in 1926, about 50 miles southeast from Grozny, was completed on Oct. 26, 1930, for 3000 bbl. of clean oil at a total depth of 3630 ft. The oil tests 40° Bé. and contains 30 per cent. gasoline, 45 per cent. kerosene and 16 per cent. paraffin; it is derived from the Maikop formations, stratigraphically below the producing formations of the older Grozny fields. The new well is in the Benoi district near the village of Sterch-Kertich on an anticline which is reported to be 12.5 miles long and 2 miles wide. Though located near Grozny, the district is almost impassable and will require the construction of roads, supply depots and pipe lines in a most unfavorable, mountainous and wooded country. For this reason production

from the Benoi field is not expected to reach important figures until the summer of 1932. Upon discovery, seven new wells were ordered started in the new field, and the 1931 program calls for 33,000 ft. to be drilled there; also in the Old and New Grozny fields eight wells were ordered to be drilled to the deeper Maikop formation.

Drilling in Grozny fields is falling 40 per cent. behind the program, because of disorganization of transport and supply. In the wildcat districts of Grozny the drilling is falling fully 60 per cent. behind the Five-year plan figures.

North Caucasus—Maikop—Maineft

Further developments of the C horizon in the Maikop field uncovered very large reserves, with a naturally flowing production of considerable magnitude, up to 30,000 bbl. per day. Unfortunately, however, a huge gas and oil gusher well, No. 45, caught fire on July 26, 1930, and at this writing is still burning. This fire was preceded by a large wild oil gusher, No. 15, which covered a large area of the Maikop oil field, and the forests around it, with a thick film of oil, with the result that the fire of well No. 45 assumed at first catastrophic proportions. At the present time only well 45 is burning and the fire is localized, but practically all operations in the Maikop field have been suspended. The well is beginning to issue oil and gas through the fissures away from the casing and therefore is in the same class with the famous Rumanian gas well which has been burning for the last two years.

The importance assigned to the Maikop field is indicated by the Five-year plan figures, which require 18,000,000 bbl. production in 1933. Also, a pipe line is projected from Maikop to Touapse, to have a capacity of 13,000,000 bbl. per year, and it is also planned to increase the present capacity of the Maikop-Krasnodar pipe line from 1,600,000 to 4,800,000 bbl. per year. Similarly, the capacities of refineries in Touapse and Krasnodar will be increased. A carbon-black plant is under construction in Maikop. The actual development and production in this field during 1931 will depend to a great extent on the extinguishment of the fire in well 45.

In Kuban Province, at the base of the Taman Peninsula, near Varenikoff (20 miles northwest from the railroad station at Krimsky) a well spudded on July 8, 1930, on the Adagum anticline, encountered oil saturation at 1250 ft. and started periodical overflowing on September 4. The actual possibilities are yet undefined. Twelve wells are to start in this area during 1931.

North Caucasus

The North Caucasus geologically is one province, and the finding of oil from Kerch-Taman peninsulas to the Caspian Sea, after but little

real wildcatting, indicates the huge importance of the area. Indeed, at this time the North Caucasus has indications of being one of the most important potential reserves of the world. From western Crimea to Baku, some 1000 miles, north of the Crimean-Caucasian Mountains and covering all of the northern Crimean Peninsula and north Caucasian steppes, roughly to the line from Rostoff-Don to Astrakhan, is an area underlain by several oil-bearing formations. Development of the western portion of this province is of tremendous importance, as it is within a few miles from the export points on the Black Sea and also near the industrial centers of Southern Russia. It is a question of but a few years before Maikop and Kuban fields will produce more oil than Baku and Grozny fields.

Emba-Embaneft

The great distances from the Emba fields to points of consumption and the new discoveries in the Maikop and Kuban area, delayed the developments of this salt-dome province considerably. It is probable that the active work in the Emba fields will be indefinitely postponed, as it should be, though the current Five-year plan calls for production of 20,000,000 bbl. in 1933, and anticipates supplying this remote district with no less than 500 drilling rigs in the next three years. The development of the Emba is an uneconomical proposition at this time, beyond supplying local very small requirements of petroleum products, and it is quite apparent that the Central Bureaus in Moscow will have to reduce appropriations for the Emba district.

North Saghalien-Saghalienneft

The developments on Saghalien Island during the past year were of routine character. Okha field was the only producing pool. In the coming year the Soviet trust plans wildcatting at Katangli, Liangeri and Goromai. It is also planned to build a small refinery at Khabarovsk, in Far Eastern Siberia, with a capacity of 1,500,000 bbl. per year, to treat Saghalien crudes. The Japanese concessionnaires temporarily suspended wildcat operations on Saghalien. Evidently the present cheapness of crude oil and its apparent abundance are not conducive to expensive operations in far away and questionable areas.

Ural-Uralneft

The developments in the Ural district so far have been eminently unsatisfactory. About 20 wells are now drilling in that area, but only two very small producing wells have been completed to this date. Wildcat wells at Kizel and Cherdin extended the oil-bearing area 200 miles to the south from the original Chusovsky-Perm district. The limestones

show only good saturation with both oil and gas, but fail to produce oil in commercial quantities. Wildcatting in the Perm-Ural Province will continue, but as a result of failures near Perm, it will spread to the Volga River on the west, and extend south to Orenburg.

Russian Turkestan

Two gushers were completed in the Shor-Su field during 1930. Well 13 had an initial production of 1100 bbl. per day from 1000 ft. and well 14 came in for 2500 bbl. per day from 1200 ft. Previous wells in Turkestan were very small; the larger discoveries just made are greatly increasing the potentiality of this province and give promise that Turkestan eventually may depend on its own liquid fuel supply. This in turn will release greater volumes for export from the Baku fields, which at the present time are supplying Turkestan.

Supply Problem

The problem of supplying the oil fields, and the wildcat wells in particular, with vital equipment, is of greatest importance in Russia today. As a matter of fact, no further progress is likely to be made in the oil industry until the supply problem is completely and thoroughly reorganized. Currently, the planning bureaus of individual fields and trusts are making out requisitions to Moscow for two years to come, and the central commissions there revise these demands as they please. The result is that while some equipment is available in overabundance, other equipment is completely absent. In many instances drilling rigs, otherwise complete, lack engines; casing and drilling pipe arrive months late, or the few cars that are available in wildcat districts go foraging for food supplies which have been overlooked, thus tying up the supply of equipment. At the present stage the supply problem may be considered to be in a state of chaos, and under the existing form of government only the complete separation of the supply management from the producing trusts, and its unification on the basis of a separate organization, responsible directly to Moscow, could solve the difficulties.

Transportation

Though of relatively minor importance elsewhere, in Russia, the oil transportation problem is extremely difficult. The main trunk pipe lines are built exclusively for export. The Baku-Batum (510 miles) kerosene pipe line has a capacity of about 8,000,000 bbl. per year, the new Baku-Batum crude oil line has a maximum capacity of 12,000,000 bbl. per year, while the Grozny-Touapse (325 miles) crude oil line has a capacity of 8,000,000 bbl. A short Grozny-Caspian Sea line has a capacity of 5,000,000 bbl., thus the total present maximum pipe line capacity is about 35,000,000 bbl. per year. This capacity will not be

changed much by the beginning of 1933, because no new lines are being built now, though several are under discussion. The development of Kuban-Maikop fields will result in short lines to the Black Sea, as already noted, and this will add some 20,000,000 bbl. to the total. Possible completion of a pipe line to Don coal district may add another 10,000,000 bbl., but that line, even if authorized, could not be completed in time to affect transportation of 1933 production.

The main channel of moving oil and its products from Baku and Grozny to the interior markets is via Caspian Sea and the Volga River system. The navigation is open only part of the year, the Volga being frozen during the winter months. The 1929 navigation season anticipated a movement of 40,500,000 bbl. in Caspian Sea tankers, whereas actually only 38,800,000 bbl. were shipped. Originally it was planned to ship 49,000,000 bbl. during the 1930 navigation season, but later that figure was reduced to 38,500,000 bbl. (?), and finally 39,750,000 bbl. were moved by Caspian Sea tankers, thus exceeding the plan. Incidentally the navigation season was open this year an unusually long time, allowing additional and not considered trips.

The remaining transportation is accomplished by tank car shipments, primarily from Grozny to the points in southern Russia, and also from Baku to points in Trans-Caucasia. Any large increase in railroad shipments is out of the question because of the small carrying capacity of individual tank cars and the disorganization of the Russian railroad system. The return of empty tank cars usually is delayed indefinitely.

Summing up the transport capacity, with probable increases by 1933, the following *maximum* figures are arrived at:

	Barrels
Grozny-Touapse pipe line	10,000,000
Baku-Batum pipe lines (2 built, 1 planned)	30,000,000
Maikop and Kuban-Black Sea lines	30,000,000
Caspian Sea-Astrakhan (from Baku, Grozny and Emba) (absolute maximum)	100,000,000

Even if the railroads can move as much as 30,000,000 bbl. in 1933, the total transportation capacity will just reach 200,000,000 bbl., therefore the planned production of 330,000,000 bbl. appears too high as checked against transportation facilities.

Refining

During 1929–1930, 107,000,000 bbl. was run to refineries—86.3 per cent. of total production, as compared with 77,500,000 bbl. in the preceding year. The 1931 plan anticipates an increase in total runs to 162,000,000 bbl., or 91.4 per cent. of planned production.

Gasoline recovery showed some improvement in Grozny, reaching 19.4 per cent. of total runs, but it declined in Baku to 5.1 per cent., due to

underproduction of light Surakany crude; kerosene recoveries were 24.8 per cent. in Baku and 18.7 in Grozny. A very insignificant amount of gasoline was produced by cracking in the past year, though officially several units were completed early in the year; it is reported that considerable difficulties are continually encountered after construction of cracking stills, and that their work so far is not at all satisfactory, because local staffs are as yet unfamiliar with the process.

Table 2 shows total production of refined products in the Soviet Union for the last two years.

Table 2.—*Total Production of Refined Products in Russia*

	1928–29, Bbl.	1929–30, Bbl.
Gasoline	10,100,000	14,000,000
Kerosene	18,600,000	22,000,000
Lubricating stocks	5,300,000	7,000,000
Fuel, and other heavy oils	43,800,000	60,000,000

Marketing

Table 3 indicates the home distribution of petroleum products for 1928–1929 and 1929–1930, and also shows the rate of increase. The larger demand for kerosene has been due primarily to the increased number of kerosene-burning tractors. This particular demand for kerosene is estimated to have increased at the rate of 116.5 per cent. in 1929–1930, while domestic demand increased but 14 per cent.

Table 3.—*Interior Distribution of Petroleum Products in Russia*

	1928–29, Bbl.	1929–30, Bbl.	Increase, Per Cent.
Gasoline	1,100,000	1,800,000	58.7
Kerosene	11,500,000	15,700,000	36.2
Light lubricating stocks	2,100,000	3,600,000	71.3
Heavy lubricating stocks	1,400,000	1,650,000	18.0
Fuel oil	39,000,000	49,000,000	26.9
Total	55,100,000	76,750,000	30.7

It is fully anticipated that an increase of 30 per cent. per year in interior consumption of petroleum products will continue, even if the country progresses very gradually.

The export trade of the Soviet Union continued its expansion, though relatively far poorer results were obtained because of the increase in the shipments of heavy oils. Table 4 shows 1929–1930 exports from Russia, and the rate of increase over the preceding year.

Table 4.—*Russian Export Trade*

	1929–30, Bbl.	Increase Over 1928–29, Per Cent.
Gasoline	12,000,000	36.5
Kerosene	6,200,000	4.8
Lubricating oils	1,800,000	2.9
Heavy oils (fuel, gas and crude)	15,000,000	43.0

Labor

The labor situation became very acute at the close of the 1929–1930 operating year. The Soviet statistics indicate that the turnover of labor in the Baku fields during the 1929–1930 operating year reached a total of 101,060 men (54,476 men hired and 45,684 men discharged or left) with the average employment of 50,978 men through the year, indicating a turnover of 196.4 per cent. The third quarter alone of the 1929–1930 operating year had a turnover of 64 per cent., as compared with a turnover of but 28 per cent. in the second quarter, indicating a most remarkable labor situation. Such "fluidity" resulted in lowering of the quality of work, because of the lack of experience, and was reflected more particularly in skilled labor. The Soviet leaders advance several theories to explain this situation, but apparently dissatisfaction and the lack of discipline are the two primary factors.

Conclusions

The Russian oil industry is a major disturbing element in the international oil situation, because the programs of the next few years call for radical increases in production, refining and the exports. The planned increases will not be realized, and, as a matter of fact, the Old Russian oil fields may find it difficult to keep on increasing their production indefinitely, and will shortly begin to show considerable declines. The new fields, though certainly present, will not be opened rapidly, because of disorganization caused by centralized planning bureaus and also by the lack of transportation facilities. It does not appear probable therefore that the Soviet Government will be able to continue increasing its exports, unless it forces reduction of domestic consumption. An export distributing agreement with the Soviet Union appears as possible of achievement, because the Soviet government can be shown that for smaller volume of exports it can secure more foreign currency if it does not engage in price-cutting operations. If, however, the Soviet Government chooses to continue on current market-breaking policies a general embargo by all countries will become the only alternative.

DISCUSSION

(H. J. Wasson presiding)

H. J. Wasson,* New York, N. Y.—There must be many questions to ask Mr. Zavoico. Russia and Rumania are more or less the uncertainties which we must all watch closely. What happens in those countries has a decided bearing on our economic welfare.

V. R. Garfias,† New York, N. Y.—Is it not a fact that in Baku there really is one field under the other, and therefore there is not one well to a third of an acre? Are you not dealing in Baku with conditions like those in some of the California fields? It may be the same square mile at the surface, but you are tapping different fields at various depths.

B. B. Zavoico.—This is undoubtedly true. However, even though there are several horizons in the fields of Baku district, only certain few horizons are most prolific in the individual fields, like horizons V and VI in the Surakany. Fundamentally speaking the question is that of rational development, or one of forced drilling and overdevelopment, and even a perfunctory survey will indicate the latter to be the case, due directly to complete failure of all wildcat developments.

V. R. Garfias.—What is the total thickness of the Baku producing series?

B. B. Zavoico.—The total thickness of the Baku producing series, the Pliocene "Oil Measures," is 6000 ft. There are about 30 producing horizons, but only few of them are very prolific at any one place, with the exception of the Bibi-Eibat field where the saturation of the "Oil Measures" is extraordinary.

V. R. Garfias.—You really have one field under the other, when you have so many thousand feet of producing sands.

H. J. Wasson.—You can qualify that a little further, Mr. Zavoico. In that 6000 ft., what is the total thickness of the strictly oil section; that is, the producing pay?

B. B. Zavoico.—About 75 per cent. of sand and about 25 per cent. of shale, also there are two or three continuous water-bearing horizons, and some portions are poorly saturated. I would consider that originally about 2000 ft. could be figured as oil pay, but at this time, after 40 years of development, only the lower undeveloped horizons can be considered as virgin, because the undrilled areas of older fields are undoubtedly affected by reduced gas pressure and water-flooding. Currently about 250 ft. of section can be considered as available for new development, the remainder being in various stages of depletion, flooding and requiring a considerable amount of work for bringing oil to the surface and further separating it from bottom settlings and water.

H. J. Wasson.—Do those intermediate water horizons make it impossible to produce it as a single zone?

B. B. Zavoico.—Yes, they do. Only certain few horizons can be and are produced by one well.

H. J. Wasson.—It is hard to visualize the production curve going up at a steep angle, under those conditions. I think it is very encouraging, at least from the viewpoint of our domestic industry.

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* Consulting Engineer.

† Foreign Department, Henry L. Doherty & Co.

There is another interesting point in Mr. Zavoico's paper. He referred several times to the accomplishment of drilling, the number of feet per year. That gives us a sort of rule for correlating the cost of oil, and also the productive possibilities. For instance, Mr. Zavoico, did you mention 1,000,000 ft. as the estimated footage drilled in 1930?

B. B. Zavoico.—In Baku alone it was 1,320,000 feet.

H. J. Wasson.—Did you calculate the total figure for the country?

B. B. Zavoico.—I would make an approximate estimate of 2,000,000 feet.

H. J. Wasson.—Along that line, perhaps you can tell us how many rigs are working in the whole country.

B. B. Zavoico.—About 500 rigs. Actual drilling takes four to five times as long in producing fields, and fifty times as long in wildcats, as compared with our practice.

H. J. Wasson.—With 500 rigs running in Russia it figures out about 250,000 bbl. annual production per active rig, which is more or less comparable with Oklahoma. It certainly proves in a general way that it is a real oil country, in spite of the presumed inefficiency which exists. They seem to be getting a very satisfactory production for active drilling rigs in operation, on the average.

B. B. Zavoico.—Upon detailed analyses it is really not comparable, because all drilling is taking place in proven extraordinarily rich oil fields, while in Oklahoma drilling is done in fields that very often do not furnish on the average more than 10 bbl. initial production wells, and in addition much wildcatting is conducted continuously, while in Russia real wildcatting is still unknown.

J. M. Lovejoy,* New York, N. Y.—I did not quite understand whether Mr. Zavoico feels that the production can not climb to the 1933 estimated figure because it just is not there, or whether it is simply a physical impossibility to drill the number of wells, with facilities and supplies available, to obtain that amount.

B. B. Zavoico.—The reserves of oil in Russia can be considered as unlimited, but the method of development of new fields, as well as complete disorganization of transport and supplies, precludes the possibility of rapid increase in newly discovered areas, while old fields are being exhausted rapidly.

H. J. Wasson.—Well, unless they step out into the new territory in the North Caucasus and get into some of that virgin territory, is there not a possibility that they can not even maintain the present production from the older fields?

B. B. Zavoico.—It is not only a possibility, but even a probability.

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* President, Mexican Seaboard Oil Co.

Petroleum Development in Rumania during 1930

By Ionel I. Gardescu,* Pittsburgh, Pa.

(New York Meeting, February, 1931)

During the summer of 1930 the average daily oil production of Rumania registered a new peak at 128,000 bbl. per day. The estimated potential production as of September, 1930, was as high as 235,000 bbl. per day. During the latter part of the year, by mutual agreement, the operators decided to curtail their output to about 100,000 bbl., which brought the average for the year to 116,600 bbl. The total production for 1930 was 41,572,000 bbl. (last month estimated) as compared with 35,757,000 bbl. for 1929, or an increase of 16.3 per cent. over last year's production. The production for the last 10 years is given in Table 1.

Table 1.—*Production of Petroleum in Rumania*

Year	Production, Bbl.	Increase over Previous Year, Per Cent.	Year	Production, Bbl.	Increase over Previous Year, Per Cent.
1921	8,617,000	12.5	1926	24,009,000	39.9
1922	10,117,000	17.5	1927	27,120,000	13.0
1923	11,226,000	11.0	1928	31,617,000	16.6
1924	13,713,000	22.1	1929	35,757,000	13.1
1925	17,158,000	25.1	1930	41,572,000	16.3

The curtailment of production was prorated per company, based on its total estimated potential production as of September, 1930, and not per field. As a consequence, at present there is little development of protected or slightly productive areas; *viz.*, Arbanasi, with an average production of 1750 bbl. per day, dropped to less than one-third after curtailment came into effect. Moreni, with an average production of 92,000 bbl. per day, while producing 58 per cent. of the country's total output in 1929, went to 67 per cent. at the beginning of 1930 and to 75.2 per cent. towards the end of the year.

The modified Mining Law of 1929 is still in effect. This law withdraws the restrictions set on foreign capital by the law of 1924. As a consequence a large percentage of proven state land was alloted through competitive bidding to foreign companies. The Romano-Americana (Standard of New Jersey) acquired several leases in the Boldesti and

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Ceptura areas where the company already has large holdings. Leases were also acquired by two newly organized companies, the Prahova, controlled by the Azienda Generala Italiana Petroli, and the Romano-Africana, controlled by the Service Petroleum Co., Ltd. Two mergers were made: The Sirius and Concordia, both controlled by the Compagnie Financière Belge des Petroles and the Columbia and Aquila Franco-Romana, both French capital.

Table 2 gives a list of the major operating oil companies, their invested capital, the name of the holding company, and the potential capacity of production measured under governmental supervision as of September, 1930.

TABLE 2.—*Producers of Oil in Rumania*

Company	Invested Capital	Holding Company	Potential Production, Bbl. per Day	Potential Production, Per Cent.
Astra Romana	$8,475,000	Royal Dutch Shell	22,900	15.34
Concordia-Sirius	4,375,000	Cie. Fin. Belge de Pet.	19,826	13.28
Steaua Romana	6,250,000	Steaua Romana, French-British Rumanian	18,673	12.50
Unirea	937,000	Phoenix Oil & Transp. Co.	19,661	13.17
Romano-Africana	3,650,000	Service Pet. Co. Ltd.		
I.R.D.P.	3,290,500	French & Rumanian Banks	9,734	6.52
Credit Minier	3,142,000	French & Rumanian Banks	15,731	10.54
Romano-Americana	3,125,000	Standard Oil of N. J.	11,461	7.67
Columbia-Aquila Franco Romana	2,600,000	Omnium Int. des Pet.	9,296	6.23
Prahova	1,087,500	Azienda Gl. Italiana Petroli	3,205	2.15
Subsolul Roman	468,750	Rumanian Capital	3,351	2.24

Drilling and Production Methods

Rotary is gradually replacing the Canadian and the cable tool drilling systems. The Canadian system uses a percussion movement on the bit to accomplish the drilling, while water or light mud is circulated through tubing of small size to the bottom of the hole. The system has the advantage of a relatively small initial cost and permitting the setting of a large number of protective strings of casing which, a few years ago, were required by the mining officials. Its chief disadvantages are the almost perpetual fishing jobs and the lack of protection for drilling in high gas-pressure fields. Within recent years the government has accepted the mudding in of a formation as sufficient protection to shut off water, gas and oil sands, and the required number of water strings has been reduced to a minimum. This fact, together with the high pressures in the deeper pays of the Ochiuri-Moreni-Piscuri fields, is chiefly responsible for the expansion of the rotary drilling system.

The picturesque but primitive and hazardous method of producing wells by bailing or swabbing has come to an end. The government passed

a law in June, 1930, requiring that all wells which stop flowing naturally shall be produced either by air-lift or gas-lift or pumping. For many years operators held that pumping could not be used efficiently in Rumania because of the large quantities of sand produced with the oil.

The new mining law makes it obligatory to collect all gases produced with the oil and to extract the liquefiable products before delivering the gas for combustion purposes.

In Rumania competitive drilling has been at its worst. It is not unusual for the peasant's land tract to measure several thousand feet, or even miles, in length but only a few feet in width. The patch extends from the road to the river and whenever the owner of the land dies he divides the acreage into still smaller strips, all extending from the road to the river as before. Under the new mining law, the subsurface rights for most of the undeveloped land belonging to the government, the average size of a lease is from 20 to 40 acres. Even in areas where the landowner retains his subsurface rights, the law requires that such land be incorporated in a larger block for leasing purposes. Such a lease of *comasare* has recently been acquired by the Columbia Co. at Ceptura.

A minimum distance of 260 ft. is required between offsetting wells and 130 ft. from the lease boundry. Wells with too high a gas-oil ratio are shut in as a protective measure from the field. The operating gas-oil ratio is determined for each field separately. Competitive drilling still persists, chiefly in Moreni. In Ceptura the three leading companies, the Romano-Americana, Steaua Romana and Astra Romana, have agreed to exchange leases among themselves, thereby unifying their holdings.

Very spectacular has been the fire of the Romano-Americana well 160 at Moreni, which started May 28, 1929 and continues to burn. Three attempts have been made to extinguish the well by the tunnel method. In each case an explosion in the tunnel stopped the progress of the work. In September, 1930, through a recently completed offset well, water was pumped into the sand at over 2000 lb. pressure. Instead of affecting the burning well, the water broke through into another near-by well.

The curtailment program now in effect provides no drilling restrictions, although an obvious decrease in field activities is to be noted. During the first half of 1930 an average of 100,000 ft. of hole were drilled per month, while during the second half the footage was reduced by more than half. In October, 1930, the subsidiaries of the Standard of New Jersey and the Royal Dutch Shell suggested that all drilling activities be suspended beginning Nov. 1, 1930 for an unlimited period of time. The suggestion was not accepted by the other operating companies. Drilling has been suspended by the Steaua Romana in the District of Bacau (small Oligocene production) and has been greatly reduced in the District of Buzau and in other noncompetitive drilling fields.

State Land

Any company or individual has the right to do prospecting on any state land, either by geological or geophysical methods, upon payment of an annual fee of $60. Exploration work involving wildcat drilling is given by exclusive permit for a definite area to the first company applying for such permit.

Not until the new law came into effect did the foreign companies apply for any exploration permits. During 1930 both the Romano-Americana and Astra Romana applied and obtained several such permits, ranging in size from 800 to 2000 acres each. Wildcat drilling was unusually intensive at the beginning of 1930 but slowed down towards the end of the year. The Romano-Americana is drilling two wildcat wells between Boldesti and Ceptura at Pleasa and Urlaţi. The I. R. D. P. has proved new acreage south of Gura-Ocniţei while the Astra Romana is prospecting to the north of Ochiuri. Other prospecting wells are being drilled at Scaiosi, Copaceni, Podeni and Glodeni.

The Oil Fields

With the exception of the District of Bacau, which produces a small amount of Oligocene oil, all of the production of Rumania comes from two main horizons, the Dacic and Meotic, both of Pleiocene (Tertiary) age. The Dacic is overlain by unconsolidated fresh-water rocks and is productive only where it is in contact with intruding salt stocks. The Dacic is also a fresh-water formation and includes several soft coal beds of low carbon ratio. The oil occurs in unconsolidated, medium coarse grained and fairly well sorted sands. About 2000 ft. of clay separates the Dacic from the Meotic, the second important oil horizon. Fig. 2 shows the relationship between the Dacic and Meotic in four of the main oil areas of Rumania. The oil in the Meotic is considered of primary origin and production has been secured from structures where there is no evidence of a salt mass.

The salt is intruded as a vertical dike, probably several thousands of feet deep, extending east and west for several miles and only a few hundred feet wide. The surrounding sedimentary rocks dip north and south on either side of the salt while the crest of their intrusion with its sinuous outline determines the extent of the individual pools which are lined up along this general uplift. Two-thirds of Rumania's oil production comes from one such structure, the Ochiuri-Gura Ocniţei-Moreni-Bana-Piscuri oil fields. Bana and Moreni were the first units to be developed in this area. The production came from the Dacic on the south side of the structure. On the north flank, the Dacic being partly eroded and unproductive, the wells were carried down to the Meotic, which proved to be very prolific. It was only towards the end of 1928 that the Romano-Americana completed a well on the southern flank

of the salt to the Meotic. This discovery was followed by intense drilling and the Royal Dutch Shell soon had a daily production from this area of about 15,000 bbl. per day. Close to the salt the average depth of the producing horizon is 5000 ft., but this depth increases rapidly to the south, the beds dipping at an angle of 50° to the south. Because of this fact all the wells were drilled along the top of the structure and are producing with as high gas-oil ratio as 50,000 cu. ft. per barrel.

The field as a whole from Gorgota to Piscuri is over 7 miles long and less than 1½ miles wide. Recent developments were the deeper Meotic production south of the salt, all along this structure, the extension of the field to the east (Piscuri) by the Romano-Africana, to the south of Gura-Ocniţei by the I. R. D. P. and the newly organized Prahova (Italian) company, and to the northwest of Ochiuri by the Astra Romana.

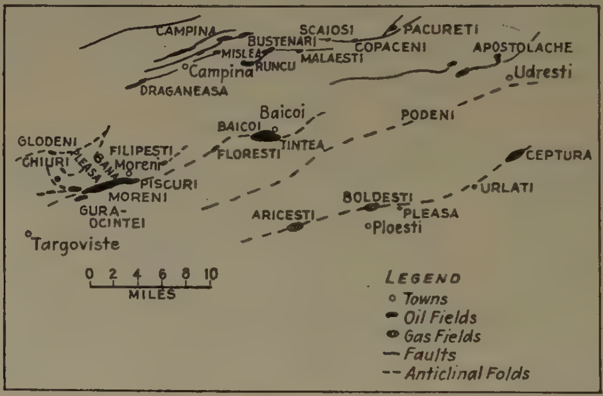

FIG. 1.—RUMANIAN OIL FIELDS.

About 10 miles east of Moreni is the Baicoi-Tintea field. The structure of the field is very much the same as that of Moreni. The production comes mostly from the Dacic while the Meotic, which was tested by several wells, has not proved as prolific as in the Ochiuri-Moreni-Piscuri area. Little development is going on in a newly proved area between Baicoi and Tintea. Several wildcat wells were drilled between Baicoi and Moreni and some production was obtained from Filipesti de Padure.

South of Baicoi and west of Ploesti is the Aricesti gas field, producing from the Dacic. Another gas field is Boldesti, 4 miles north of Ploesti. The Romano-Americana and Astra Romana have recently completed several deep wells in the Meotic, which contains a high-grade oil with high-pressure gas. Some of the gage pressures recorded read as high as 2600 lb. on a 6000-ft. well. Baroid weighted mud is used for drilling. In all other high gas-pressure fields the companies are dispensing with the use of baroid, claiming that a carefully drilled well in which the gas-cut mud is continuously replaced with fresh mud will never blow out. Ari-

cesti and Boldesti have broad anticlinal structures with gentle dips and apparently no salt core. The Boldesti discovery wells prove up a large area which might extend much farther to the east towards Ceptura, the structure of which lines up well with that of Boldesti. West of Ceptura and east of Boldesti the Romano Americana is drilling two wildcat wells at Urlati and Pleasa. Ceptura is controlled by the Steaua Romana, Astra-Romana and Romano-Americana.

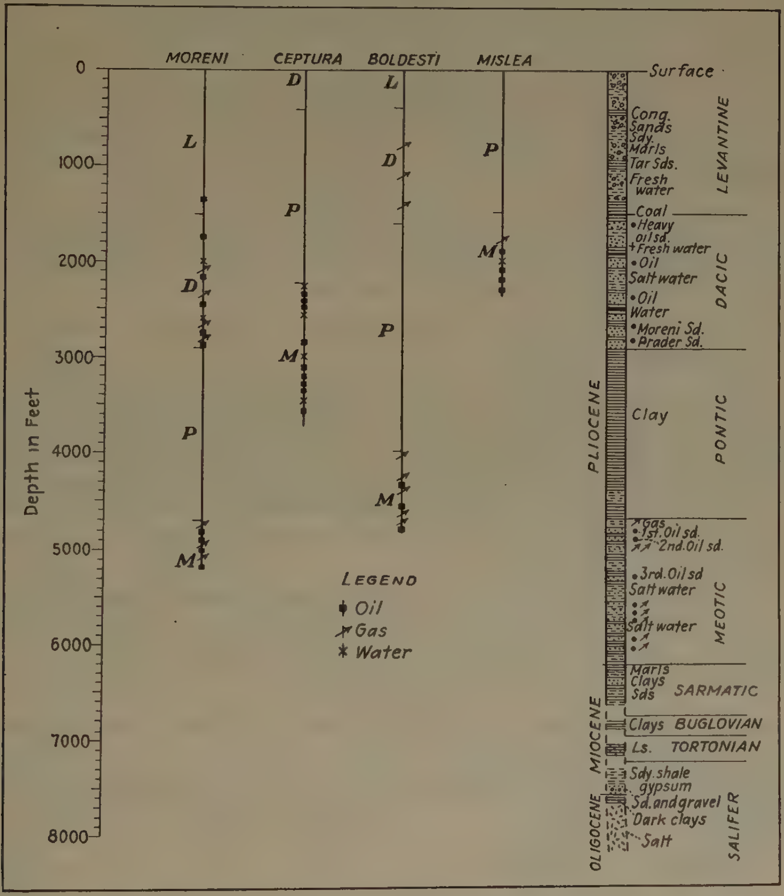

FIG. 2.—RELATIONSHIP OF DACIC AND MEOTIC IN RUMANIAN OIL AREAS.

To the north of Baicoi is another important oil-producing area extending east and west from Campina. The oil occurs along terraces and monoclines badly faulted and generally dipping to the south. The geology of the area is more complex than that of the salt structures and the production more spotted. The area is being developed to the east and exploration wells are drilled at Malaesti, Scaiosi, Copaceni, Podeni, and so forth.

Some of the leases given out at auction by the government carry with them the obligation for wildcat drilling in areas far remote from present proven territory or from the leased acreage. In this manner the government expects to obtain a satisfactory evaluation of its possible oil land throughout the country. Such exploration wells are to be drilled by the Columbia Co. in the Neamţ district, northwest of the Bacau district development, and by the Sirius Co. in the Putna district between the Bacau and Buzau district developments. It will be interesting to watch the results of these tests and the advisability of the method.

DISCUSSION

D. C. Barton,* Houston, Texas.—Have geophysics had any positive success in Rumania?

I. I. Gardescu.—Geophysics have been applied with fair success in Rumania. In the Boldesti gas field, it is interesting to note that before the field was developed Schlumberger made a geophysical survey of the area for the Steaua Romana which checked nicely with later information obtained from well records.

D. C. Barton.—And it actually was developed on the basis of that work, and not on the basis of anything else?

I. I. Gardescu.—The Boldesti field was developed by the Romano-Americana (Standard of N. J.) and the Astra-Romana (Shell) on the basis of geological field evidence. Some details of the structure as drawn from well logs check nicely with the structure map outlined by Schlumberger. These details were not known from the study of surface outcrops and I did not know anything about the geophysical survey for the Steaua until a few years later when Schlumberger's office in New York sent me a copy of their Boldesti map.

H. J. Wasson,† New York, N. Y.—Rumania seems to be the most promising section of the world for an immediate and alarming increase in production, as far as I can see from the papers that have already been presented. Are the oil prospects limited to the area shown in Fig. 1 of your paper?

I. I. Gardescu.—There are several other structures, mostly untested, and it is hard to predict what their production would be.

Member.—Is there any oil being found in connection with the gas fields in Transylvania?

I. I. Gardescu.—Only gas.

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* Consulting Geologist and Geophysicist.
† Consulting Engineers.

Petroleum in the Dutch East Indies

By Fred B. Ely,* New York, N. Y.

(New York Meeting, February, 1931)

The first recorded production in the Dutch East Indies was in the year 1893 but seepages of oil were known to exist in North Sumatra, East Java and the east coast of Borneo at least as early as 1880. During the

Table 1.—*Producing Areas and Production of Crude Oil, Dutch East Indies*

Area	Daily Production, Bbl.	
	1924	1929
North Sumatra	4,050	8,230
South Sumatra	9,840	25,700
Northeast Borneo (Tarakan Dist.)	10,750	18,016
Southeast Borneo (Sanga Sanga Dist.)	22,840	38,284
East Java	7,520	12,800
East End Island of Ceram	1,000	880
Total daily average	56,000	103,900

Area	Crude Oil Production, Bbl.	
	1929	1930
North Sumatra	3,000,000	3,710,642
South Sumatra	9,370,177	12,422,584
East Coast Borneo	20,558,879	18,708,468
Java	4,674,944	4,762,238
Ceram[a]	320,928	269,916
Sarawak	5,277,000	5,832,000
	43,201,918	45,705,848

[a] Estimated.

Of the above amount the	
Royal Dutch produced	36,006,079
Nederlandsche Koloniale Petroleum Maatschappij (subsidiary of Standard Oil of New Jersey)	3,867,769
Total Dutch East Indies	39,873,848

* Consulting Geologist.

period of 1890–1900, fields were brought into production in all of these widely separated regions. In 1900 the production of the East Indies was approximately 2,253,000 bbl. (daily average 6200 bbl.) this amount being equal to 3.5 per cent. of the production of the United States, which was 63,620,000 bbl. In 1930, the output of the East Indies was equal to 4.5 per cent. of the production of the United States and 2.9 per cent. of the world's production.

There has been a steady increase in production since 1900 up to the present yearly rate of approximately 45,700,000 bbl., or a daily average

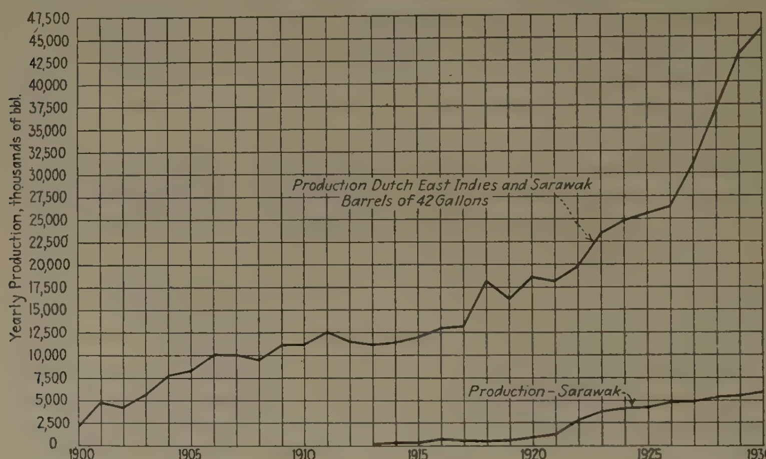

FIG. 1.—PRODUCTION, DUTCH AST INDIES AND SARAWAK. BARRELS OF 42 GALLONS.

of 125,000 bbl. This increase has been fairly consistent excepting during the period 1911–1917, when there was only a slight increase, and for the period of 1927–1929 (three years) when there was an increase of about 20 per cent. each year, which was due largely to the bringing into production of the Talang Akar field in South Sumatra.

The principal producing areas and production figures are listed in Table 1.

GENERAL GEOLOGY

South Sumatra.—Most of the oil produced in South Sumatra is from the district of Palembang. Some oil is produced in Djambi but thus far the amount is negligible. In Palembang the oil pools occur in a series of fairly parallel anticlinal ridges which trend northwest-southeast in the northern part of the district, swinging to a more nearly east-west direction in the southern half. Folds are for the most part narrow with domal areas on closed anticlines and in some cases asymmetrical in form with the steepest dips on the western or mountainward side. Producing

horizons are in sand lenses in the Middle Palembang formation of Lower Pliocene age and Lower Palembang and Goemai shales of Miocene age. The greater production is from Lower Miocene formations; in fact, this holds good for all of the East Indies. Up to the end of 1927 there was practically no production at a greater depth than 3000 ft. and most of the production comes from the levels between 1000 and 2500 feet.

In the past few years deeper drilling has been carried on, notably a well put down to over 7000 ft. by the Niam company in South Sumatra, which found production in the Goemai shales at this depth. The gravity

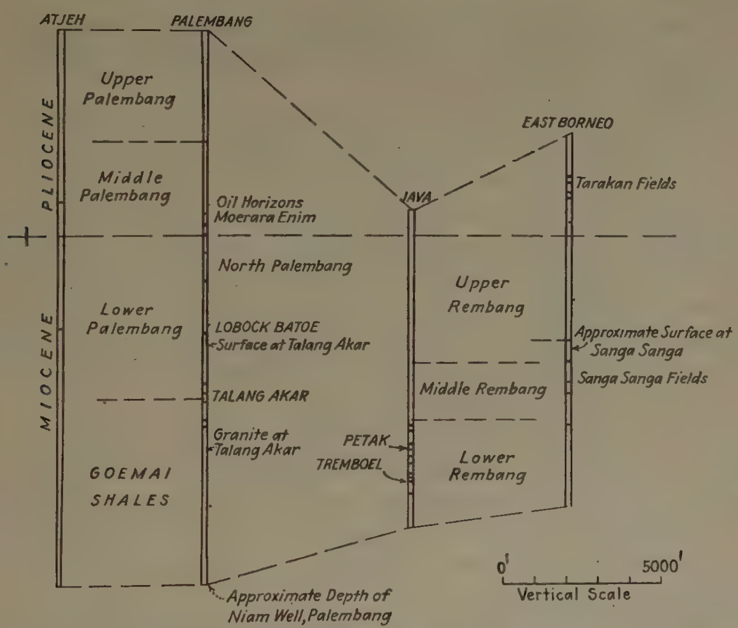

FIG. 2.—GENERALIZED CROSS-SECTION, DUTCH EAST INDIES.

of the oil in Palembang ranges from 36° to 40° Bé. and is usually of a high paraffin content.

In the district of Palembang the estimated area of producing, proven and prospective oil lands is placed at 686,080 acres. There are 45 anticlines with closure, 27 of which were productive or producing oil in 1924. The accumulation of oil is controlled by structure, there being no oil produced from synclines or from structures that are not well defined.

North Sumatra.—There are four main producing structures in North Sumatra-Residency of East Coast—situated close to the shore. The production at the beginning of 1931 was at a daily rate of 11,000 barrels.

East Java.—The producing fields of East Java are included within an area 75 miles long in an east-west direction and 25 miles wide. Within

this area there are 37 anticlines with closure, of which 25 were productive in 1924, or had produced some oil.

Production is obtained from sand lenses in the Middle and Lower Rembang formations of Lower Miocene age. Anticlinal structures are sharply folded, with a considerable amount of faulting. Hot salt water and mud volcanoes are not uncommon. The most prolific pools are situated along a central zone, which is bordered on the north and south by far less productive areas. Extending from the coastal region southward there are three fairly well defined zones. There are from the north to the south:

1. Coastal zone of marls, clays, chalky limestone and sandy limestone with numerous coal seams. Some gas is produced. The width of this zone is from 8 to 12 miles.

2. Middle zone of chalky limestone (rich in corals) interbedded with clay and sandy limestone. No coal and no commercial oil or gas. The width of the zone is from 6 to 8 miles.

3. Southern zone of impure limestone (Platten calc) interbedded with marls and sandstones and in certain areas overlain by thick deposits of blue and black marls. Contains no coal. Most of the production is within this zone, which is from 12 to 15 miles wide. This zone on the south merges into the more closely folded sediments intruded by volcanic rocks and terminating in the southern volcanic mountain chain. The gravity of the oil varies from 27° to 47° Bé.

Borneo.—Folds in the Tertiary formation in the coastal region of Borneo are recognized in widely separated localities and a considerable amount of drilling has been done, but production of oil has been confined to two areas; namely, the Sanga Sanga district in the southeast and the Tarakan district in the northeast. The greater percentage of production has come from the former district.

In the Sanga Sanga district the pools are situated on domal areas along a narrow closely folded ridge with dips on the east up to 35° and on the west up to 62° or more. Formations of Lower Miocene age are exposed along the crest of the producing structures. These formations consist essentially of shales and sandstones with interbedded impure limestones and lignites. Younger rocks are exposed both north and south of the producing fields along the axis of the regional fold. While all the production has come from one anticlinal ridge, the accumulation is governed by domal areas or closed anticlines situated on the major structure. While there is a succession of folds from the coast inland, the one nearest the coast, or the most eastward fold, is the only one that is rich in oil. The pools are within an area not more than 15 miles long and up to the end of 1930 it is estimated that the production is over 160,000,000 bbl. of oil. The oil is in general of three distinct grades, consisting of a heavy oil from shallow horizons at depths of less than 300 ft., gravity

TABLE 2.—*General Geology, Oil-producing Regions, Dutch East Indies*

Period	Formation	Region East Coast Borneo General Description	Formation	Region North Central Java General Description	Formation	Region South Sumatra General Description
Pliocene	Kembang	Gray and red sandy clays, ferruginous and sandstones, lignite and resin, coal from Kembang and Balik Papan. Oil from Balik Papan. Production at Tarakan. Thickness 2000–3000 ft.		Clay marls No oil.	Upper Palembang	White to gray tufts interbedded lignite seams. Poorly stratified clays gray to blue in color. No oil. Thickness 3900–5500 ft.
					Upper Palembang	Blue to chocolate brown clays, marls and sandy shales. Beds of lignite. Tuffs. Coal deposits mined by Government. Oil at Moeara Enim. Thickness 1200–2000 ft.
Miocene	Moeara Djawa	Soft gray clays and sandstones. Myogypsina polymorpha and Lipidocyclina. Coal from Moeara Djawa. Oil from Moera Djawa. Thickness 2000–3000 ft.	Upper Rembang	Sandy marls. Thin limestones and sandy limestones. Interbedded marls and marly shales called globigerine marl zone. Lower part well stratified. Amphistignia Carbitina—Pulvinulina—Rotalia No oil. Thickness 1400–1500 ft.	Lower Palembang	Blue to black clays, marls, thin bedded sandstones, sandy shales—impure limestone beds—Globigerine marls and glouconitic sands. Beds of tuffs. Oil in Northern Palembang. Thickness 4000–6000 ft.
			Middle Rembang	Limestones and sandy marls. (Platten calc formation) also reef limestones. Coral and lithothamion limestone. Interbedded limestone, sandy shale and sandy limestone. Rich in formanifera. Very little oil. Thickness 1400–1500 ft.		
	Sanga Sanga	Sandy clays and shaly. Clays with plant deposits and slatey limestone. Myogypsina thecideaformis and Lepidocyclina. Coal from Sanga Sanga. Oil from Sanga Sanga. Thickness 4000–4500 ft.	Lower Rembang	Lime clay group—chiefly marls with clays and shales. Called Wonotjola marls. Most important oil horizon. Thickness 1900–2000 ft.	Goemai (Telisa shales in Djambi)	Dark and blue black shales with interbedded thin limestones also sandstone beds separated by thin shale members. Chalky orbitoid limestone in S. W. Palembang. Shales petroliferous at surface. Hard shales. Oil production throughout. Thickness 6000 ft.
Oligocene	Prangat	Limestone, clayey shales. Modular clays. Coal from Prangat. Some gas.		Not differentiated.		Orbitoid limestones from Batoe Rodja. Clay marls and marly sandstones north of Moeara Doea.
Eocene				Limestones in highly folded mountain area.		Clay shales with coal. Upper Rawas. Coal-bearing breccia and conglomerates near Moeara Duwa and Upper Rawas.

15° to 16° Bé., 13 per cent. paraffin and 0.12 per cent. sulfur; at depths of less than 850 ft., gravity 30° to 32° Bé., 7.2 per cent. paraffin and 0.11 per cent. sulfur; at depths greater than 1000 ft., gravity 34° to 35° Bé., 19.1 per cent. paraffin and 0.07 per cent. sulfur.

Tarakan District of Borneo.—The Tarakan field proper is situated on the island by that name in the extreme northeastern part of Dutch Borneo. Included in this district are the islands of Boenjoe and Mandoel, upon which some oil has been developed but where there is no commercial production. Oil has also been found on the island of Sebatik, which lies off the east coast of the extreme southern border of British North Borneo.

The Tarakan oil is of heavy asphaltic grade of 17° to 25° Bé. gravity and has been used essentially as a fuel oil. Recent developments have found a lighter oil at depth.

Sarawak.—The oil obtained in the Miri district on the northeastern border of Sarawak occurs in sand lenses in formations of Lower Miocene age. The gravity varies from 18° to 39° Bé. In some oil the sulfur content is reported as being 0.4 per cent. Commercial production began in 1912.

Celebes.—While there has been no production from the island of Celebes, oil seeps and asphaltic deposits are known to exist along the east coastal area and also for a shorter distance on the west coast. Petroleum emanations are reported to occur in rocks of Lower Tertiary and Upper Mesozoic age. Very extensive asphaltic deposits have been developed on the island of Boeton and are said to be found in Upper Triassic rock. They are reported to have considerable potential value.

New Developments

The outstanding developments for the year of 1930 were:

1. The discovery of oil in the island of Poeloe Boenjoe (near Tarakan).
2. The development of deeper producing horizons of light oil in the Tarakan district.
3. The bringing in of a large well in North Sumatra (Residency of East Coast).
4. The finding of granite in wells in the Talang Akar anticline at depths of 3000 feet.
5. Development of asphaltic deposits in Boeten district of South Celebes in rocks of Triassic age.
6. Production in Goemai shales at 7000 ft. depth in Palembang district found by Niam company.

Government Laws

Most of the oil concessions that have produced oil were granted under the old mining law (prior to 1918) and run for a period of 75 years. This law was superseded by regulations which went into effect in 1918 and

since that time no concessions have been granted except by special government legislation. Some concessions were granted on the basis of the government's participation in the profit, a notable example being the Djambi concession of South Sumatra, whereby the government entered into a partnership agreement with the Royal Dutch Shell Co. Exploitation did not result in the finding of important production. Also, in the past few years some concessions have been obtained in Palembang district by the Nederlandsche Koloniale Petroleum Maatschappij (subsidiary of the Standard Oil Co. of New Jersey).

Mining and prospecting permits have been granted (since 1918) in large numbers but they have little or no value as commercial propositions, since there are prohibitive restrictions which practically prevent the economic production of oil and gas. Where properties can be operated on concessions granted under the old mining law, taxes and royalties on production are reasonable.

Motor Vehicles

In the year 1929 there were 81,528 motor vehicles in the Dutch East Indies, of which 62,846 were passenger cars. This represents an increase of over 130 per cent. since 1925. The price of gasoline in Java and Sumatra averaged 35 c. per gallon during 1930.

Imports and Exports

The principal sources of imports are the United States, Straits Settlements, the United Kingdom and Germany. The products imported are listed in Table 3. Exports are principally to British Malaya, Australia and New Zealand, China, Japan, British Mediterranean possessions, British India and the Philippines.

Table 3.—*Imports and Exports, Dutch East Indies and Sarawak*

	Netherlands East Indies Year of 1929[a]		Sarawak, Year of 1927	
	Imports	Exports	Imports	Exports
Crude petroleum, bbl.	812[a]	130,948		1,525,973
Kerosene, bbl.	539,183	4,304,131	26,239	525,636
Gasoline, bbl.	142,307	10,308,793	5,774	944,743
Fuel oil		9,668,069	546	1,474,066
Lubricating oil and grease, bbl.	116,897	2,556,670		
Lubricating oil only			4,258	69
Yellow grease				2,245
Paraffin wax, lb.	2,017,208	133,955,904		
Petroleum asphalt, metric tons	25,442			
Petroleum coke, metric tons	12,772			

[a] The figure for crude petroleum imported by Netherlands East Indies is for the year 1927.

Dutch Geological Survey

The Dutch government maintains a highly scientific geological survey and mining bureau at Weltevreden, Java. Geologic maps showing general structural trends and areal geology can be obtained of all of the important coastal areas that produce oil or have possibilities of production. Paleontological studies of the Tertiary formations are especially valuable, because this branch of the work has been carried to a high state of perfection. The technique of surface examination by the petroleum geologist is based upon the structural maps furnished by the department. Without these maps it would be a long and tedious task to determine anticlinal structures purely by surface exposures, since outcrops are few and far between, excepting along the river beds, and a detailed examination requires painstaking and elaborate preparations. With the aid of these maps the work is simplified. The procedure is usually to select an area where regional folds occur and the details of closure and structure are determined by the aid of test pits put down to bedding planes at depths of 5 to 15 ft. by contract coolie labor in the area to be examined. Control lines are run at right angles to the axial trend and test pits are spaced 500 to 600 ft. apart.

The Mining Bureau is very deficient in the matter of figures relating to the individual fields, such as current and past production, size of wells, depths of the producing horizons, area of the fields, etc. In fact, current statistics of production as we know them in the United States are not to be had. This policy is dictated largely by the attitude of the Royal Dutch interests who have enjoyed practically a monopoly in the Dutch East Indies and they have not felt inclined to give information that would be available to outside sources.

The publications of the Mining Bureau would no doubt have a much wider circulation if it were not for the fact that they are published in the Dutch language, which has a very restricted usage.

Operating Conditions

Methods of drilling and operation of the fields have improved materially in the last decade. Rotary and cable tool drilling is carried on by the best approved American methods, American skilled labor being much in evidence, although European drillers have been adept in picking up the best oil-field practice. Unskilled labor is cheap but inefficient, there being five to six Malay helpers for a drilling rig.

Future Possibilities of the Dutch East Indies

There is considerable prospective area in the Dutch East Indies, particularly in Sumatra, Celebes and the east coast of Borneo, which may have possibilities of yielding fields that would have a material effect upon the production. There is, however, very little chance of the imme-

Fig. 3.—General geologic map, Dutch East Indies.

diate increase in production being marked, unless the policy of the Dutch government changes in regard to the granting of oil concessions. Even though new pools may be found on some of the concessions recently granted, since development is controlled by one company, there is little likelihood of production being forced beyond market requirements.

DISCUSSION

(*H. J. Wasson presiding*)

A. A. Holland,* Toronto, Ont.—I would like to ask the price of gasoline and crude oil.

F. B. Ely.—Gasoline was 35 and 36¢., average 35, I believe. It has been very much higher than that. A few years ago it was around 45 cents.

A. A. Holland.—What is crude oil?

F. B. Ely.—Crude oil has no posted price as such, since there is none sold. Oil is shipped from Tarakan as fuel oil but no price has been quoted.

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* Consulting Engineer.

Petroleum in the Indian Empire*

By Eric J. Bradshaw, Berkeley, Calif.†

(New York Meeting, February, 1931)

For several hundred years the petroleum industry has flourished in Burma and at the close of the eighteenth century there were over five hundred producing wells in the Yenangyaung field. These were laboriously dug by hand and were exceedingly primitive, yet even today a small part of India's total production is obtained from hand-dug wells. The Indian Empire, the cradle of the oil industry, today produces but an unimpressive fraction of the world's supply of petroleum, not because the size of her contribution has diminished, but because it has remained more or less stationary while other countries have far outstripped her during the prodigious increase in the world's production of petroleum in recent years. Though for the past 10 years the total production in India has been remarkably constant, it has become increasingly difficult to maintain this output and at any rate from the older fields a slow decline may be anticipated unless new productive horizons are discovered. Production figures for the 10 years 1920–1929 (the last year for which figures are available) are given by fields in Table 1.

Crudes of Burma and Assam

The bulk of India's production comes from the Yenangyaung and Singu fields, from which the crudes are very similar, the only important difference being that the oil from the Singu-Yenangyat structure contains a higher percentage of lighter fractions. The Burma crudes resemble that of the Panhandle of Texas and have a high content of solid paraffin, though strictly speaking the oil is of mixed base with a low content of asphaltum. With the exception of the negligible production from Sabe, the Burma crudes do not require dehydration; the sulfur content is very low and is innocuous. A small amount of naphthenic acids occurs in the kerosene and intermediate oil fractions while the lubricating fraction is practically free from acid. The ash content is low and the average A.P.I. gravity of mixtures of Yenangyaung and Singu oil is 36.4.

Burma crudes require only light refinery treatment and practically all the fractions are merchantable. Part of the gasoline supply is stripped

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TABLE 1.—*Annual Production from Principal Oil Fields of India and Burma*

AMOUNTS GIVEN ARE IMPERIAL GALLONS[a]

Locality	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Assam										
Badarpur	8,151,322	4,461,473	4,038,731	3,555,377	3,277,829	4,281,878	3,210,838	1,912,593	2,730,576	2,036,275
Digboi	5,206,850	5,069,461	5,343,910	7,448,719	9,697,420	14,448,534	20,887,697	22,604,187	28,745,932	31,497,054
Masimpur								25,485	25,780	5,360
Burma										
Akyab	9,770	9,780	8,886	8,628	7,014	7,169	6,331	5,627	5,260	1,980
Kyaukpyu	30,075	27,869	16,211	16,721	14,708	14,361	15,103	15,452	15,227	15,034
Minbu	3,835,198	3,706,831	3,940,416	3,915,140	3,829,044	3,248,566	4,533,420	5,199,950	6,101,822	5,815,252
Singu	95,256,753	104,167,749	92,107,998	87,476,474	79,938,430	95,262,519	95,745,504	98,691,437	113,986,736	91,481,726
Thayetmyo	91,329	66,372	2,319,835	1,818,584	1,717,653	1,320,009	974,620	999,500	727,322	746,221
Upper Chindwin	1,022,766	1,182,782	1,210,914	1,311,644	1,474,898	1,385,977	1,255,840	1,825,120	2,308,880	2,796,560
Yenangyat	3,176,231	2,510,533	2,413,416	1,700,035	1,594,517	1,562,444	1,778,041	1,844,946	3,072,222	17,606,935
Yenangyaung	176,285,048	184,420,141	179,741,493	175,158,721	181,636,739	160,027,885	145,731,612	137,322,012	135,969,794	134,936,816
Punjab										
Attock	50,640	59,306	7,362,315	11,804,560	11,383,240	8,047,200	6,230,320	10,667,600	12,254,160	19,208,880
Total	293,115,982	305,682,297	298,504,125	294,214,603	294,571,492	289,606,542	280,369,326	281,113,909	305,943,711	306,148,093
Value[b]	£7,954,611	£5,603,958	£7,202,494	£7,007,908	£7,559,229	£7,740,727	£7,305,509	£4,421,468	£4,314,207	£4,800,448

[a] 1 Imperial gallon = 1.201 U. S. gallons.
[b] £1 = $4.86

from the wet gas in the fields, the Burmah Oil Co. preferring compression plants, while the Indo-Burma Petroleum Co. has built an efficient absorption plant at Yenangyaung. The gasoline obtained by distillation requires no treatment. Two grades of kerosene are produced by the Burmah Oil Co., of which the higher grade product is treated with bauxite. The gas oil and light distillates are blended in the cheaper kerosene, which has an enormous sale as an illuminant throughout India. Paraffin wax is one of the principal products; it is sweated and treated with bauxite. Lubricating oils are lightly treated with acids. No fuel oil is produced from the Burma crudes, as they are too valuable for the purpose. The principal companies have their refineries near Rangoon. The fields of the Burmah Oil Co. are connected by pipe lines, a 4-in. line running from Yenangyat to Singu, which is connected with Yenangyaung by an 8-in. line; the total production is brought to Rangoon through a 10-in. line about 275 miles long. The other operating companies transport their field productions to their refineries in flat-bottomed barges, which are lashed in pairs to steamers on the River Irrawaddy.

The crude from Digboi in Assam resembles that from Yenangyaung, but contains a much higher percentage of solid paraffins and has a higher asphaltum content. The Badarpur crude is a curious natural fuel oil and contains no gasoline or solid paraffins. The asphaltum content is low and the solid residuum resembles rosin. The heavy distillates are poor in lubricating quality and cannot be corrected by chemical treatment.[1] The crudes of Assam are treated in the refinery at Digboi, to which extensions have recently been added, together with provision for cracking.

As in China, kerosene is the most important petroleum product on the Indian market, though the demand for gasoline is steadily increasing. Despite the large indigenous supply, over 100 million gallons of kerosene were imported into India from other countries during 1929; of this total, Russia and Georgia supplied about 38 million gallons and Persia and the United States of America about 23½ million gallons each. The imports of fuel oil into India are also increasing; almost 115 million gallons were imported in 1929. Of this, 89 million gallons came from Persia, 10 million from the Straits Settlements and about 16 million from Borneo. Paraffin wax is the most important petroleum export from India; in 1929 the total export was a little over 64,000 tons valued at over £2,300,000. The bulk of this was taken by the United Kingdom, about 7500 tons coming to the United States of America.

Sources of Indian Crudes

The petroleum resources of the Indian Empire are confined to the sites of three ancient gulfs:

[1] W. J. Wilson: *Jnl.* Inst. Petr. Tech. (1924) **10**, 227–255.

1. The Burmese gulf, covering what is now the basin of the lower Irrawaddy and its main tributary, the Chindwin, and opening southward into the Bay of Bengal.

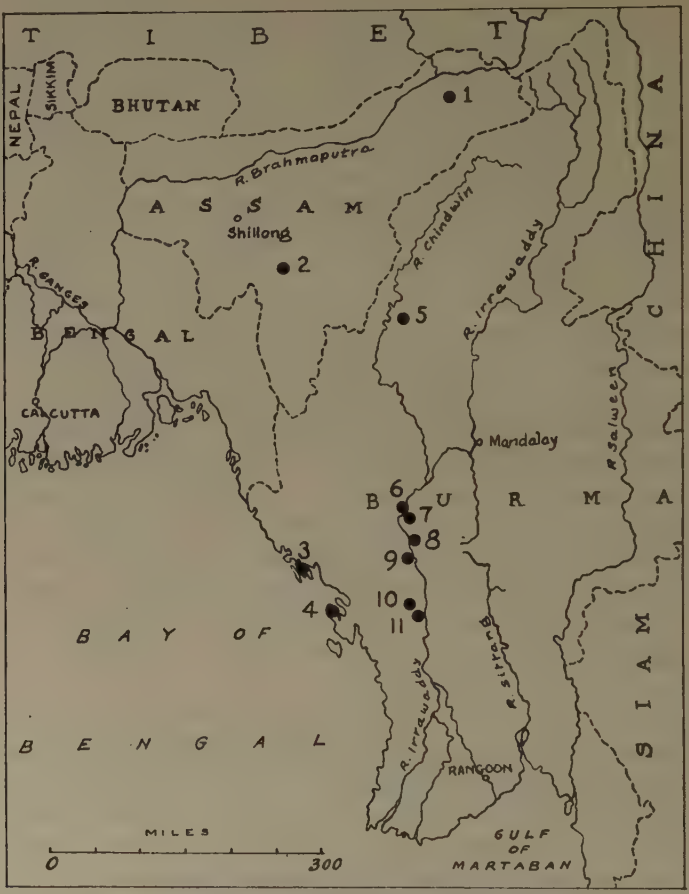

FIG. 1.—OIL FIELDS OF BURMA AND ASSAM.

1. Digboi.
2. Badarpur.
3. Akyab.
4. Kyaukpyu.
5. Indaw.
6. Yenangyat-Sabe.
7. Singu-Lanywa.
8. Yenangyaung.
9. Minbu.
10. Yenanma (Thayetmyo)
11. Padaukpin (Thayetmyo).

2. The Assam gulf, occupying the middle portion of the present Brahmaputra and debouching into the Bay of Bengal through the modern Meghna basin; and

3. The Punjab-Baluchistan gulf, extending along the base of the Himalaya northwestward from a point opposite Naini Tal and curving around through the Potwar plateau south-southwestward through what are now the Baluchistan hill ranges to the Arabian Sea.

In all three areas the oil is associated with Tertiary strata, and has had probably similar conditions of origin in all cases. In Burma it is known to occur in beds of Nummulitic age, but by far the greatest number of seepages and all the fields of importance are in the next highest geological series, to which there is every reason to suppose the oil is indigenous. In Assam oil is found in a similar series. In the Punjab, on the other hand, it is the Nummulitic which is the predominant oil-yielding series, ind although the only supplies which have so far proved of economic amportance are found in the series above, there is good reason to suppose that the oil has migrated up from the Nummulitic below. Whether in Burma, Assam, or northwest India, the occurrences of petroleum are always associated with an anticlinal structure.[2]

The geographical position of the fields in Burma and Assam areas is shown in Fig. 1.

Yenangyaung Field, Burma

Yenangyaung is the most highly developed field in the Indian Empire and is chiefly remarkable for its long life and the high concentration of oil per acre. The producing area is less than $1\frac{1}{2}$ square miles in extent, yet during this century alone over three billion gallons of valuable crude oil have been produced from the field. Its prolific nature is probably due to its position in the center of a wide gathering ground, whence the oil may have become concentrated by lateral migration, and partly to long-continued, favorable conditions of sedimentation, as is indicated by the presence of many petroliferous horizons throughout the thick section of Pegu beds. In structure the field is a gentle elongated dome, about $\frac{1}{2}$ mile wide and 4 miles long. The crest maximum is attained in Khodaung, to the south of which there is a saddle followed by a change of pitch, which gives rise to a minor domal area in Beme. The fold is slightly asymmetric with the gentler dip on the eastern side, a fact of which the importance has only recently been recognized. Though production, especially in the Reserves, has been declining for some years, the field is by no means moribund, and possibly may yet be rejuvenated by the discovery of new producing horizons at greater depths than those exploited at present.

Political considerations have prevented the development of the field as a unit, for on the annexation of Upper Burma by the British, while the wells owned directly by the Burmese king were sequestered, the ownership rights of the twinza-yos[3] were recognized. The sequestered

[2] Sir E. Pascoe: *Rec.* Geol. Survey of India (1925) **57**, 259–260.

[3] A twinza-yo is a hereditary well owner, a member of one of 24 Burmese families to whom the Burmese kings had granted the right to mine for oil. Subject to the permission of the others, a twinza-yo might alienate his rights in his well sites, and most of them have done so on a royalty basis, while, in some cases, retaining the right to sink a hand-dug well on the leased site.

areas were subsequently leased to the Burmah Oil Co., which later also obtained many sites in the Reserves. Two areas were demarcated and set aside for the twinza-yos, who were individually allotted a number of circular sites 60 ft. in diameter, within each of which a well might be dug. Thus one company held blocks to the north and south of the structure and also the domal area known as Khodaung. The Twingon Reserve of a little less than 300 acres separates the northern blocks from Khodaung which in turn is cut off from the southern leased areas by the Beme Reserve of about 150 acres. As the large profits obtainable by modern methods of drilling became known, there was a rush to lease these circular well sites from their owners and, as was natural, the lessees' object was to secure sites in good strategic positions rather than adjacent sites which could be compounded into blocks. There inevitably followed a race to the productive sands, with all the evils attendant on close competitive drilling. In Yenangyaung at present there are over 2750 wells, of which 185 are Burmese hand-dug wells, and the Reserves are probably the most closely drilled areas in the world.

Correlation of the producing sands at Yenangyaung is a matter of extreme difficulty which is largely due to lateral variation in the texture and thickness of the sands. As the sands are closely spaced, it is also likely that errors due to the drift of wells have resulted, as elsewhere, in anomalies in correlation. There are few distinctive markers and micropaleontology and water analysis give inconclusive results. In general the producing horizons are classified as shallow, intermediate, lower and deep sands. The shallow sands give small productions from two groups at depths of about 350 and 650 ft., respectively. The intermediate sands extend from below the normal first isolation at about 1000 ft. as far as a suitable cementing point above a producing sand of wide extent which occurs at a depth of about 2400 ft. near the top of the structure. The lower sands are those below this to the top of a strong gas sand, which is found at a depth of about 3000 ft. Any sands below this horizon are known as deep sands.

Little is known at present regarding the possible existence of undeveloped deep horizons. A syndicate has drilled a test well in block 4 S. to a depth of over 5000 ft., which is said to have encountered gas and oil at a depth of over 5000 ft., but at the end of 1929, the most recent information available, the mechanical condition of the well had prevented testing of the value of these sands. Further south, in block 6 S., the Burmah Oil Co. has drilled a test well to a depth of over 4000 ft. No large accumulations of oil were proved but the well encountered considerable volumes of gas. During 1929 a number of wells were completed and put to production from horizons correlative with the 2500 to 2800-ft. zones of the field in an area situated outside and to the east of the productive limits of the shallow sands.[4] This additional production has been

[4] L. L. Fermor: *Rec.* Geol. Survey of India (1930) **63**, Pt. 3, 307–308.

obtained as a consequence of a realization of the asymmetric nature of the structure at Yenangyaung.

The exploitation of the shallow sands has been a feature of the last five years. The zone was passed by unprotected when the field was first developed. Though 4 bbl. per day is considered a good initial production from a shallow well and the average production is less than 2 bbl. per day, it nonetheless pays to exploit the zone, as these shallow wells can be rapidly and cheaply drilled by cable tools with tripods in place of the usual derrick. Scrap casing is used for lining the bores, and they are cheaply pumped on jacks from central pumping powers. In point of fact, about 16 per cent. of the total production from the Yenangyaung field is obtained from these shallow sands and this has caused an apparent and temporary arrest in the natural decline of the field.

As a natural result of the congested conditions in the Reserves, the decline in production there has been more severe than in the leased blocks held by the Burmah Oil Co. For some years all wells in the Reserves have produced under a slight vacuum equivalent to 5 in. of mercury. Though this suction was first applied as a measure of economy to stimulate the production of gas for fuel purposes, so that the quantity of crude oil burned under boilers might be reduced to a minimum, it is claimed to have also prolonged the producing life of the wells. As production from wells in the Reserves approached the economic limit, application was made for permission to increase the amount of vacuum applied to the wells. The request has so far been refused, and opinion is still divided as to the respective merits of vacuum and repressuring as secondary methods of stimulating recovery. The operating companies have for some time been considering the feasibility of a cooperative scheme for repressuring the Beme Reserve. There are many obvious difficulties in repressuring a congested area where neighboring wells are held by different operators and where most of the wells are group producers from several different horizons.

Initial productions of over 50 bbl. per day are now uncommon at Yenangyaung, except in Khodaung, where larger strikes are sometimes made, partly because of its high position on the structure and partly because the leased areas have been less intensively developed than the Reserves. A further contributing factor is that unit development has been possible in the leased stocks where the Burmah Oil Co. has carried out a great deal of exact research on the effects of pressure control. For some years they have experimented with extensive repressuring of the shallow sands. A very high percentage of the injected gas is recovered and recycled. Repressuring has now been extended to the intermediate and lower sands. Some interesting work on the effect of repressuring with heated gases has been done recently, while another question under investigation is the extent to which secondary recovery methods, such

as repressuring, result in an actual increase in ultimate production or merely cause an acceleration in production with no effect or even an adverse effect upon ultimate production.

The Yenangyaung field has been almost completely electrified, the power being generated by means of gas sold by the operators on a cooperative basis. The congested conditions in the Reserves, where almost every well interferes with the production of its neighbors, are unsuited to rotary drilling and cable tools are generally used. Rotary wells are more common in the leased blocks, and, while some are driven by electric motors, steam power is generally preferred in view of the danger of a cessation in circulation in a deep rotary well consequent upon a temporary failure in the supply of current. A feature of the field is the large number of wells that are pumped by means of jacks. When wells require cleaning, as they frequently do, it is common practice to pull the tubing by means of portable power units. The Burmah Oil Co. carries heavy equipment from the warehouses at Nyaunghla to the field by means of an aerial ropeway.

Despite the congestion in the Reserves, it is probable that Yenangyaung is one of the most efficiently operated fields in the world. There are certainly few in which greater precautions are taken to prevent damage to the sands by flooding or from other causes. This has been made possible by cooperation between the several operators, whose field superintendents and representatives of their geological staffs, together with a member of the Geological Survey of India, constitute an Advisory Board, who advise a senior government official, known as the Warden, upon matters pertaining to the development of the field. In addition to the Burmah Oil Co., which controls over 80 per cent. of the total production of the field, the chief operating companies are the associated British Burmah Petroleum Co., and Rangoon Oil Co. and the Indo-Burma Petroleum Co.

Singu (Chauk) Field, Burma

From the point of view of production, the Singu field ranks second in Burma, but it constitutes the principal reserve supply of petroleum in the province, and is steadily overhauling the older field. The greater part of the field is worked by the Burmah Oil Co., which draws upon it for only such supplies of crude as are necessary to stabilize the throughput of its refinery at Rangoon. For this reason the production figures do not adequately indicate the potential capabilities of the field.

The Singu field is situated at the southern end of the anticline on which the Yenangyat and Sabe fields also lie, the total length of the fold being a little less than 39 miles. At the southern end of the fold the crest rises rapidly; in the square mile block north of this the pitch is about 6°; farther north the rise is more rapid until the maximum is reached about

$\frac{2}{3}$ mile to the north. The crest maximum is maintained for about one mile and there is then a gentle northerly pitch as far as the River Irrawaddy. The fold is sharply asymmetric, the dip at the western flank being about 21°, this angle decreasing gradually until the crest is reached, when the beds bend over rapidly to a maximum average dip of about 70°. There is a notable discrepancy between the thickness of the Pegu beds on each side of the crest. On the western limb the average thickness of the Pegu strata is about 3000 feet; in the eastern limb it is only about 1450 feet.

When compared with conditions at Yenangyaung, Singu is characterized by the regularity of the producing horizons and the equality in yield from wells producing from these sands at similar positions on the structure. The richest parts of the field are found in the neighborhood of the crest maximum, where the first producing zone occurs at a depth of from 1400 to 1450 ft. This sand gives an initial production of about 500 bbl. in block 59 N.; in the block to the north it depreciates somewhat; in block 58 N. this zone contains high-pressure gas, while oil is found again, but at a greater depth, in block 54 N. to the south. The second producing zone occurs at a depth of from 1800 to 1900 ft. near the top of the structure and there is yet another at about 3000 ft. Many wells are now producing from this zone whose margin has been found to lie within that of the shallower sand in the southern part of the field but outside it in the northern. The southern part of the field is held by the British Burmah Petroleum Co. and the Rangoon Oil Co., with which it is associated. Their wells are situated well down the pitch of the structure and as a result the producing horizons are encountered at much greater depths. Recent geological work by the British Burmah Petroleum Co. has suggested the possibility of the existence still further to the south of petroliferous horizons within reach of the drill; the question is now being put to the test by drilling. As yet no extensive accumulations have been proved below the 3000-ft. zone. A well in block 57 N., on the western edge of the productive area, was recently drilled to a depth of almost 5000 ft. by the Hessford Development Syndicate, but without encountering new deep sands.

Apart from offsetting along the boundaries of the areas held by the Burmah Oil Co. and those leased by the Hessford Development Syndicate on the west and the British Burmah Petroleum Co. on the south, the field is an outstanding example of orderly and conservative exploitation. Since production began in 1901, its development has been systematic and unhurried. Development in general is carried out from the flanks towards the top of the structure with a careful regard for pressure control, on which much experimental work has been done. Every possible measure is taken to avoid excessive gas-oil ratios even to the extent of shutting down wells in which the production of gas proved excessive.

The restriction in output has made it possible to put into practice an economical stabilized drilling program that does not fluctuate with production requirements. Wells are drilled and cemented just above the producing horizons, usually by rotary with controlled bit pressures; when further supplies of oil are required by the refinery these wells can be quickly deepened into the oil sands, usually by cable tools to avoid mudding of the sands. At the northern end of the field, where the River Irrawaddy cuts across the fold, the Burmah Oil Co. has drilled wells on piers on the foreshore, which is submerged when the river is in flood. These and many other wells in the field are pumped by jacks actuated by central pumping powers, though in some areas the wide spacing makes individual pumping units preferable.

Gas-lift has not been found suitable for all wells but where it proves economical it is adopted during the early stages of the life of the well. The electrification of the field is now almost complete, the current being brought from Yenangyaung through a transmission line some 40 miles long. It was originally intended to have power stations both at Singu and at Yenangyaung with both fields connected by a transmission line so that current might be sent in either direction in accordance with variations in power requirements and the availability of gas for fuel at any time. For this plan there has been substituted that of connecting the two fields with a gas line and actually generating the current at Yenangyaung alone. In view of the high value of the Burma crude oils it has proved economical to import oil from the distant fields of Persia rather than to burn the indigenous crude on the Singu oil field.

Lanywa Field, Burma

The Lanywa field is a structural continuation of the Singu field, being cut off from it by the River Irrawaddy. The productive area lies in an embayment of the river behind the Lanywa-Sitpin sand bank, which is a semipermanent topographical feature, deeply submerged when the river is in flood. For some years the Indo-Burma Petroleum Co. has been constructing a massive revetted embankment, designed to protect this bank, and in 1929 the work was successfully completed. A number of wells have been drilled in the protected area and have been put to production, their yield being reflected by the heavy apparent increase in the production from the Yenangyat field with which Lanywa was grouped for convenience in administration. In 1929 the field was officially notified as part of the Chauk (Singu) field and in future the production will be recorded separately.

Drilling in the Lanywa field presents some interesting engineering problems, because when the river is in flood the productive area is deeply submerged. Drilling and pumping are then conducted from special platforms built at a suitable height up the derricks, the boilers being

situated on the embankment. Careful core records have been kept of the strata penetrated by the wells, and it has been found that in this field correlation by water analysis gives good results.

The Indo-Burma Petroleum Co. is contemplating a bold scheme for the exploitation of the part of the structure that lies between Lanywa and Singu beneath the main channel of the River Irrawaddy (a river comparable to the Mississippi) and which may not be drilled into in the ordinary manner on account of interference with navigable channels and other considerations. Their proposal is to excavate deep galleries beneath the bed of the river and in panels opening from these to drill ordinary wells in underground chambers, the difficulty of bringing in wells underground at high pressures being surmounted by an adequate ventilation system of separate tunnels cut off from the workings by gas-tight doors.

Yenangyat Field, Burma

Two crest maxima on a sharply asymmetric anticline constitute the small Yenangyat and Sabe fields, which are structurally continuous with that at Singu. The western limb of the fold dips gently but the eastern is extremely steep and is overfolded in places. The Pegu rocks brought up by the fold pass northwards into barren fresh-water deposits and only the lower producing sands of Singu are included in the section at Yenangyat, so that the potential production is limited as compared with that of Singu to the south. The field reached its peak in 1903, the wells being characterized by high initial productions and rapid declines. Since that date production has declined steadily from almost 23,000,000 to 1,500,000 gal. per year. High gas pressures were originally a difficulty at Sabe, but at present production from that part of the field is very small and includes a small amount of oil won from Burmese hand-dug wells. The Burmah Oil Co. is the principal producer, with the Rangoon Oil Co. and the Minbu Oil Co. interested to a lesser extent.

Yenangyat shares with all steeply asymmetric structures the extra expense of development entailed in the lateral displacement of the crest line at depth, so that wells drilled to shallow sands high on the structure cannot be deepened to lower zones, as they would cross the crest line before these were reached. There has recently been a renewal of shallow drilling, which has served to arrest the production decline. A number of deep test wells are also being drilled in search of new productive horizons, but have not as yet encountered commercial accumulations of oil. It is not improbable that mining of the shallow productive zones may be resorted to in the future.

Indaw Field (Upper Chindwin), Burma

The Indaw field is the most northerly and the most recently discovered of the Burmese fields. In structure it is a low dome, the age of

the producing horizons being probably rather older than in the other petroliferous areas in Burma. It is held under lease by the Indo-Burma Petroleum Co., which has had to overcome considerable natural difficulties in its development. Though production dates from 1918, only the shallow sands have as yet been exploited; high gas pressures make deep drilling difficult and the field is still in the early stage of development.

The field is situated in a remote and inaccessible area. Only sternwheel steamers of very shallow draft can navigate the Chindwin River and the area is still without roads, though one is now under construction. The movement of heavy equipment in such circumstances is a serious problem, as elephant transport is expensive. During the monsoon season the area is subject to sudden and disastrous floods and is extremely malarious. Thorough and expensive measures have been taken to combat fever and production has been steadily increased to about 3,000,000 gal., the crude being sent by pipe line to Pantha, where it is refined at the company's refinery at Kindat on the River Irrawaddy, 650 miles north of Rangoon.

Thorough exploration is being conducted in other parts of the Upper Chindwin district, but as yet no new commercial deposits have been proved by the test wells now in course of drilling.

Minbu Fields, Burma

Minbu Town, Palanyon and Yethaya are small fields which, though separate, are usually grouped together. They are located along the strike of a single anticlinal structure of the Yenangyat-Singu type. The fold is steeply asymmetric and even overfolded in places. The compression of the structure is partly responsible for the narrowness of the productive area and the limitation of the oil accumulations. Other causes are the erosion of the higher potentially petroliferous horizons and the unsuitable lithology of the deeper beds.

The Palanyon and Yethaya fields are due to crest maxima on the main structure, the producing sands being comparatively deep. The shallow deposits at Shwelinban (Minbu Town) yield a small but steady supply of oil which has been held up by a slight change in the pitch of the nose of the fold

Production began in 1910 and after a decline had set in, in 1919, was stimulated by shallow drilling in the Shwelinban area where the limit of economic spacing was reached in 1929. This area presents an interesting example of economical exploitation. The shallow wells are drilled with portable equipment which is removed as soon as the well is put to production, while pumping is done by means of pumping jacks operated by central powers. The appearance of the area is probably unique in that though the field is covered with closely spaced producing wells, there is not a single derrick to cut the sky line.

Several test wells have been or are being drilled in search of deep accumulations but their progress has been obstructed by many mechanical difficulties; not least of these was a heaving mud encountered in one well in the neighborhood of one of the several mud volcanoes in this locality, which occur along the line of a transverse fault. Another test well, in the Palanyon field, has encountered oil below 2300 ft. and produces sufficient gas to meet the fuel requirements of the field. The crude oil from this well is of higher grade than is produced by the other known sands in the Minbu field and is, therefore, a valuable addition to the resources of the area.[5]

The crude oils produced from the Palanyon and Yethaya fields contain little or no gasoline and when distilled give a petrolatum residuum. In this respect they differ from and are of less value than other Burmese crudes. Palanyon and Yethaya are controlled by the Burmah Oil Co. Minbu Town is also exploited by them, and, to a lesser extent, by the British Burmah Petroleum Co. and the Yomah Oil Company.

Thayetmyo Fields, Burma

For many years past a good deal of exploratory drilling has been carried out in the Thayetmyo district but without the proving of any large accumulations of petroleum. There are small producing fields at Padaukpin and at Yenanma but their production is unimportant. There have long been a few Burmese wells at Padaukpin, and in 1920 the fields were developed by the Indo-Burma Oilfields (1920) Ltd.; production reached a maximum in 1922, since when it has declined. Yenanma is now drilled up to the economic spacing limit but at Padaukpin some shallow drilling is still being conducted. There is little prospect of any large production from either field by ordinary methods of development, though exploitation of the shallow sands by mining is a possible contingency. The Yenanma crude is of good quality, resembling that of Yenangyaung.

Exploratory drilling has been renewed at Minhla, between Minbu and Thayetmyo, but so far without important results. The structure being tested is a fold immediately south of the Minbu anticline which pitches steeply to the north.

In 1924 the Indo-Burma Petroleum Co. brought in a gas well at Pyaye, a few miles south of Thayetmyo. The open flow was estimated at a little under 40 million cubic feet of gas daily, and five months elapsed before the well was eventually controlled by lubrication. The possibility of utilising the gas as fuel in the manufacture of portland cement, from suitable deposits near by, is under consideration.

Akyab and Kyaukpyu Fields, Burma

Though this region properly belongs to the Assam gulf, it is geographically situated in Burma. For many years the existence of oil

[5] L. L. Fermor: *Op. cit.*, 309–310.

deposits has been known, though the extent of the accumulations has been uncertain. A great deal of exploratory work has been carried out, both by geological reconnaissance and by testing with the drill, without the discovery of any really important accumulations. Oil seepages occur both on the mainland and on the islands off the Arakan coast, particularly on Eastern Baronga Island near Akyab, and on Ramri Island in the Kyaukpyu district. For many years a small indigenous industry has existed, the oil being won from shallow wells sunk by a method of primitive pole-drilling which is none the less more elaborate than the Burmese system of digging wells by hand.

The oil occurs in beds which are apparently of Nummulitic age; the structure is unfavorable for the existence of large accumulations of petroleum because the folds are acute and close together. Production from Akyab, never great, has steadily declined to negligible proportions, though that from the Kyaukpyu district has been better maintained.

The region is notable for its numerous gas and mud "volcanoes," many of the vents being submarine. Some are of the explosive type and occasionally the gas is ignited by frictional sparks. The celebrated Cheduba "volcano" has long been known to mariners; when burning, its flames are visible for miles at sea and were formerly erroneously attributed to volcanic activity in the region.

Digboi Field, Assam

The Digboi field is exploited by the Assam Oil Co. in which the controlling interest is held by the Burmah Oil Co. It is situated in the Lakhimpur district of Upper Assam. The productive area is about ¾ mile long and about ⅓ mile wide; the structure takes the form of an asymmetric dome with dips of from 30° to 40° on the southern limb; there are no exposures on the northern side but the dips probably approach the vertical. The productive horizons occur in the Tertiary coal measures. Production has steadily increased since drilling was begun in 1888, and there are geological justifications for the expectation of further increases in production. Extensions to the refinery at Digboi were completed in 1929 so that the expected increase might be handled, and cracking equipment is now in process of erection.

A test well is being drilled in search of deep oil-bearing horizons and at Hansapung another deep well is being drilled to test for an eastern extension of the field. Correlation is exceedingly difficult at Digboi and in this respect the field resembles Yenangyaung. The oil is a paraffin-base crude more or less saturated with solid paraffins of a high melting point, and as it also contains considerable quantities of naphtha and gas, the slightest loss of any of the lighter hydrocarbons leads to the immediate deposition of paraffin.[6] Pumping is expensive, therefore, and all pro-

[6] Sir E. Pascoe: *Mem.* Geol. Survey of India (1914) **40**, Pt. 2, 298.

ducing wells have to be cleaned at frequent intervals. Caving sands cause considerable trouble in drilling with cable tools, and rotary methods are preferred.

Badarpur Field and Other Areas, Assam

Petroleum deposits exist along the southern foot of the Khasi and Jainta Hills in the Surma Valley in Cachar. The Burmah Oil Co. has developed a small and disappointing field at Badarpur, where about 60 wells have been drilled. Production reached a maximum of 8,000,000 gal. in 1920, but has declined steadily since then. The decline from wells in the proved horizons is rapid and the wells make a good deal of water. The oil itself is of less value than most Indian crudes and is largely used for fuel, and in general the prospects of the field are not good. Two test wells recently drilled to horizons below 3000 ft. encountered oil but showed the usual abnormally rapid decline; a further deep test is being drilled.

A great deal of exploratory work has been done in other areas but as yet with negative results. The Whitehall Petroleum Corpn. carried out unfruitful prospecting in the neighborhood of the Shillong Plateau, and the Burmah Oil Co. has drilled unsuccessful tests at Dhekiajuli, Dilli and Burragolai. The same company has drilled four test wells at Masimpur in the Surma Valley, where a small production has been obtained, but, as at Badarpur, caving formations and water cause considerable trouble in drilling. A second test well is being drilled by this company at Patharia, the first having proved unsuccessful. In addition to testing with the drill, the Burmah Oil Co. has conducted extensive geological exploration in the region and maintains a specialized staff that is continuously engaged in a search for hidden structures by geophysical seismic methods.

Punjab-Baluchistan

The Attock field at Khaur in the Punjab was first developed in 1915 by the Attock Oil Co.; since then its production has steadily increased and has been especially rapid since the completion in 1922 of the refinery at Rawalpindi, which is designed to handle a daily throughput of 65,000 gal. In 1929 production increased by 57 per cent. over that for the preceding year, the bulk of the oil coming from the 3800-ft. sand, which was first proved in 1928. Heavy pressures have presented difficulties in the completion of recent wells but a further expansion in the production from the field may be anticipated.

In structure the field is an elongated, slightly asymmetric dome. The maximum dip on the flanks is about 45° while the gentle pitch attains an angle of about 7°. The oil is thought to have originated in Nummulitic beds of Eocene age and to have migrated upwards into the younger Murree beds above. The structure is exceptionally regular and correlation of the various producing horizons is simple.

Other promising structures in the Attock region, especially at Dhulian and at Kharpa, have been carefully tested, but without tangible results. Geological exploration is being actively prosecuted both in the Punjab and Baluchistan regions and especial interest attaches to the pooling of their geological resources by two of the interested companies. A geologically interesting test well was drilled some years ago by the Whitehall Petroleum Corpn. near Jhatla. The well attained a depth of over 6000 ft. without encountering exploitable accumulations of petroleum. The bore passed right through the Chinji, Kamlial and Murree beds into the Nummulitic below, the lowest 1606 ft. being bored with a Sullivan diamond drill.[7]

In Baluchistan there are numerous indications of the existence of petroleum but often either the structure is so compressed as to prevent the accumulation of large deposits, or the petroliferous horizons have been deeply eroded.

Conclusion

Despite the enormous extent of the Indian Empire, there are few areas in the world that have been so thoroughly scoured in search of commercial accumulations of petroleum. Year by year the prospects of the discovery of new and extensive fields becomes more remote as detailed exploratory work is actively but fruitlessly carried out by geological mapping, by geophysical methods and by testing with the drill. In realization of the diminishing prospects of new petroleum resources, the principal operating companies have adopted a far-sighted policy of conservative development of the known accumulations, and there is every prospect of a long continuance of output at the present stabilized figure.

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[7] Sir E. Pascoe: *Rec.* Geol. Survey of India (1927) **60**, Pt. 3, 230–231.

Petroleum Development in Africa

By W. B. Heroy,* New York, N. Y.

(New York Meeting, February, 1931)

The rapid development of transportation routes on the African continent in recent years has greatly stimulated the demand for motor fuels and this in turn has led to more extensive exploration of such limited portions of the continent as seem to give promise of commercial oil production. In 1930, however, only two countries were classed as producers of petroleum and only one, Egypt, attained any importance.

Egypt

The petroleum production of Egypt is derived from the Gemsah and Hurghada fields on the west coast of the Red Sea and the Abu Durba, on its eastern shore in the Sinai peninsula. The Gemsah field, which began to produce commercially in 1912, has now practically ceased production, owing to the invasion of salt water. The Hurghada field has been producing since October, 1914. It now has about 60 producing wells. During 1929, a deeper sand with flowing production was discovered in the eastern part of the field, producing oil of lighter gravity and free from water. The Abu Durba field was discovered by the exploration work of the Egyptian Government in 1918, oil having been found at a depth of 172 ft. This field has now 15 producing wells but a very small production. The production of these Egyptian fields over the last five years, is as follows:

	Metric Tons		Metric Tons
1926	172,881	1929	271,520
1927	184,557	1930	277,146
1928	269,324		

This oil was all produced by the Anglo-Egyptian Oilfields Ltd., a constituent corporation of the Royal Dutch Shell group.

During the year 1930 the Egyptian Government was engaged in geophysical prospecting of reserved areas along the Red Sea coast.

Other Countries

Somaliland.—A geological survey of Somaliland was undertaken by the Somaliland Petroleum Co., Ltd., a subsidiary of the Royal Dutch

* Chief Geologist, Sinclair Exploration Co.

Shell group. It was announced during the year that the results of these explorations were unfavorable and that the work would be discontinued.

Mozambique.—A large area of this Portuguese colony is included in petroleum concessions. On one of these, the Inyaminga Petroleum, Ltd., financed by South African interests, is engaged in development work. Drilling is in progress at Inyaminga station on the Trans-Zambesian Railway. When last reported the well had reached a depth of 2763 ft. without encountering commercial production, although some shows of oil had been obtained.

Angola.—The coastal plain of Angola has for many years been known to contain numerous oil seepages. During the last 15 years Companhia de Petroleo de Angola, now controlled by Sinclair Consolidated Oil Corpn., has been engaged in exploration and development work on a large concession in the colony. A number of prospecting wells have been drilled and at the present time the company is engaged in drilling a deep test at a point about 60 miles southeast of Loanda. This well had reached a depth of 3890 ft. at the end of 1930 without encountering commercial production.

Morocco.—A French corporation, Compagnie Française de Petroles de Maroc, has been engaged in prospecting in the Rharb district of northwestern Morocco since 1920. During 1930 a well being drilled near Ouezzan had reached a depth of 285 m. (935 ft.). Some small quantities of oil were reported to have been encountered.

Algiers.—The most important company operating in Algiers is the Société Algérienne de Petroles de Tliouanet, operating chiefly in the Department of Oron. It has drilled a number of wells, of which three near Medjillah are reported to be producing. The production for 1928 was 1223 metric tons. The production is obtained at shallow depths, under 500 feet.

Chapter V. Economics

Petroleum Economics in 1930

By J. Elmer Thomas,* Fort Worth, Texas

(New York Meeting, February, 1931)

If 1929 witnessed a growing realization on the part of the oil industry that supply must be balanced against demand, 1930 proved conclusively that excessive inventories constitute a price depressant even with balanced conditions. Increased attention was certainly paid to economic considerations last year, and the achievement of holding daily crude production, with a constantly mounting potential, to levels 500,000 bbl. below the output of the summer before, deserves special mention. The ill-advised accumulation, however, of gasoline stocks, at least 10,000,000 bbl. larger than necessary, nullified the restraint exercised by the producers and finally necessitated drastic downward price revisions.

An event of special significance was the appointment by the Federal Oil Conservation Board, last March, of a temporary Committee on Petroleum Economics that attempted a forecast of demand, an estimate of supply, and an allocation of the latter between the principal producing states. Thus for the first time was an economic program for an entire basic industry drafted by an independent body under the auspices of the Federal Government. The report was widely discussed and generally approved, but its schedules were not adopted by the refining division nor by oil producers in the State of Texas until too late to contribute to the industry's prosperity during 1930. If the restraint of November had been exercised in May a profitable year might have been the result. The gasoline price war in California during June, however, illustrated the point that even with a fairly sound statistical position insistent pressure to expand normal marketing outlets must result in losses to all concerned. The balanced program so painfully attained by producers must be maintained by refiners and distributors to be completely effective.

Again in November the Federal Oil Conservation Board, acting on the request of the directors of the American Petroleum Institute, called its Committee on Petroleum Economics back into existence to prepare a new estimate for the next six months. An economic program adopted in advance of the winter period of accumulating inventories may aid this large and essential industry toward the profits to which it is entitled

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and the stability which it must have to serve the public properly, but it remains to be seen whether all branches of the industry will cooperate to that end.

The industry has become aware of and receptive toward sound economic principles, appreciating the logic of a balanced program and the burden of excessive stocks. The importance of cooperative action by all branches of the industry has been definitely demonstrated. The necessity of modifying any antiquated statutes that prevent sanity in operations becomes apparent. A method for arranging a "balance sheet" for the industry has been disclosed. For these reasons 1930 must be considered as having witnessed a distinct advance in the field of petroleum economics.

Interest Rates and the Oil Industry

By Barnabas Bryan, Jr.,* New York, N. Y.

(New York Meeting, February, 1931)

During the boom period of 1928 and 1929, several oil companies took advantage of high security prices to sell stocks, thereby securing money for the company very cheaply. Few if any of those companies realized that the money received was not at all cheap in view of the fact that it was for investment in fixed assets at inflated prices.

Suppose a company borrowed twenty millions of dollars to expand its marketing facilities during the boom. It diluted its capital and acquired fixed property which could not earn its interest requirements during the following deflation and therefore consumed income from other company activities. The company also had to stand the deflation in the capital value of all the property it bought. Since the mistaken expansion during the boom accelerated the decline in net income during deflation, the financial position of the company was harmed in proportion to the amount of that expansion. Thus the company was unable to get money to buy fixed assets in the depression when all property is cheap.

The same condition holds for the company that sold common stock for the purpose of developing potential production in a newly discovered oil field. Regardless of what the ultimate value of the new field may be, potential production does not increase the net income of the company. The difficulty of meeting the enlarged dividend requirements due to the increased number of shares outstanding impairs the financial position of the company during deflation in some relation to the probability of decreased dividends. This company also is not in a position to expand during the depression when properties and companies can be bought for a fraction of their real value.

Expansion of fixed assets during boom times has been the ruin of many otherwise good companies. Some of those which most extensively bought property during the post-war boom have not yet recovered. A number of cases could be cited in sugar, leather, fertilizer and wool. This does not seem to be governed by the quality of the property bought, for examination shows the assets to have been of individual high quality in many cases. When recovery is long deferred it is likely to be true, as in sugar or textiles, that the industry has a large "potential" capacity for overproduction.

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* Pettigrew & Meyer, Inc.

The ideal policy for a company would be the sale of all practicable fixed assets during a boom and a rapid expansion when the depth of depression has been reached. In this way the assets are exchanged for more cash than they are worth and the company finds itself at the bottom of the bear market in the position of the former Standard Oil Co., which always had plenty of money to expand with when things were sufficiently cheap. One independent oil company sold properties in the Mid-Continent in 1929 and in California in 1930. Its stock has been outstandingly strong during the entire bear market.

Call Money as Indicator of Inflation

The question naturally arises of how a busy company executive can know that the situation is so badly inflated when business is expanding, orders are piling up, the stock market is apparently forecasting a continuation of good times, and economists and bankers are vying with one another to find means of justifying and extending public confidence in the situation. The answer is offered here in one simple chart (Fig. 1). It shows the high rate reached by call money in each month and a stock market average of price for comparison.

The striking feature of business guidance revealed is that when call money reaches 10 per cent. even for one day, there will be important liquidation in the stock market. The greater the delay after 10 per cent. is reached, the more drastic will be the liquidation. It is further evident that when call money passes 6 per cent., there is danger ahead which may still be avoided. Also, the chart needs no explanation of why it failed during the difficult war period or under some other unusual influence, for it carries through all conditions, continually pointing out the truth that prosperity and 10 per cent. call money cannot long exist together.

The reasons why this relationship is and must be true are too many and involved for presentation in such a paper as this, but the rules of business guidance are very clear. When call money has passed 6 per cent. companies should not make further investments unless the property is very cheap and the income fully assured. When it becomes apparent that the rise in money rates is real and that the condition will be reached which is typified by 15 per cent. call money, oil companies should sell production or refineries and even some retail stations to anyone who will buy and increase their liquid position as much as is physically possible. They should then make all they can from the remaining parts of the property and calmly wait for the assured depression during which the possession of cash will enable rapid and secure expansion. The rules for recognizing the bottom of depressions are not so easily presented. They are nevertheless equally definite.

These policies, which should apply in greater or less degree to company conduct in relation to money rates, are equally applicable to the complete industry. So long as money was cheap the industry could do many uneconomic things without especially disastrous results, but the continuation of the same mistaken policies after the rise in call money has brought the present situation will not be cured by embargoes or any other artificial measures.

At the end of 1921 stocks of all oils were 285 millions of barrels which at the end of 1923 had increased 65 per cent. to 473 millions. In 1923 the refiners learned how to crack fuel oil, which in gasoline effectiveness was the equivalent of doubling each barrel of oil in storage and each barrel of current production. This had the ultimate economic effect of stocks having increased 232 per cent. from 1921 to 1923. At the end of 1928 this total amount had increased to 614 millions of barrels of double gasoline capacity when related to 1921, or an increase of 330 per cent. At the same time an enormous potential production had been built up, the speed and sureness of drilling methods had been increased several times, the cracking capacity of the country had been overbuilt, and the condition of retailing gasoline was as bad as can easily be imagined. Yet in spite of all this, earnings were fairly good and the oil securities were well regarded during the year 1928.

After the rise in call money to 10 per cent. in July, 1928, the economic offenses of the oil industry were no worse than they had been since 1921. Oklahoma City with partial proration was not as bad as Seminole without. Kettleman Hills was no worse than the combination of Long Beach and its prolific neighbors. Abuses of marketing decreased and the control of refinery operations improved in 1929, while a marvelous degree of cooperation was developed for keeping oil in the ground. Yet in 1929 and 1930 the oil industry suffered an appalling degree of deflation.

In this comparison there is much room for thought. If it is true that the present world depression is caused by the overproduction of raw materials and dislocation of markets, it is difficult to explain how and by what miracle the oil industry was able to enjoy confidence and some prosperity for eight years during which it violated every principle of economics. Why did not bankers and investors lose confidence in oil in 1923 when stocks increased 23 per cent. and a vast surplus of production was discovered?

If it is true that the oil industry was saved from deflation for eight years because money was cheap and suffered deflation in 1929 and 1930 because there had been a run up in money rates, then the condition of the money market and the credit structure is of more importance to the average oil man than is the question of whether gasoline stocks are 30 or 60 millions of barrels on April 1, 1931.

There is much evidence to support the latter view. Fig. 1 is perfect evidence for the period it covers. As far back as the chart can be carried

without special research, the important periods of deflation are universally preceded by a run in call money to 10 per cent. or more, while the only instance of high call money at the end of a decline is that of 1907, which coincided with and concluded a great financial battle. Before the advent of adequate statistical material, history records some disturbance in the medium of exchange before every depression. An instance in point is the suspension of specie payments by the New York and Philadelphia banks immediately after the capture of Washington in 1812.

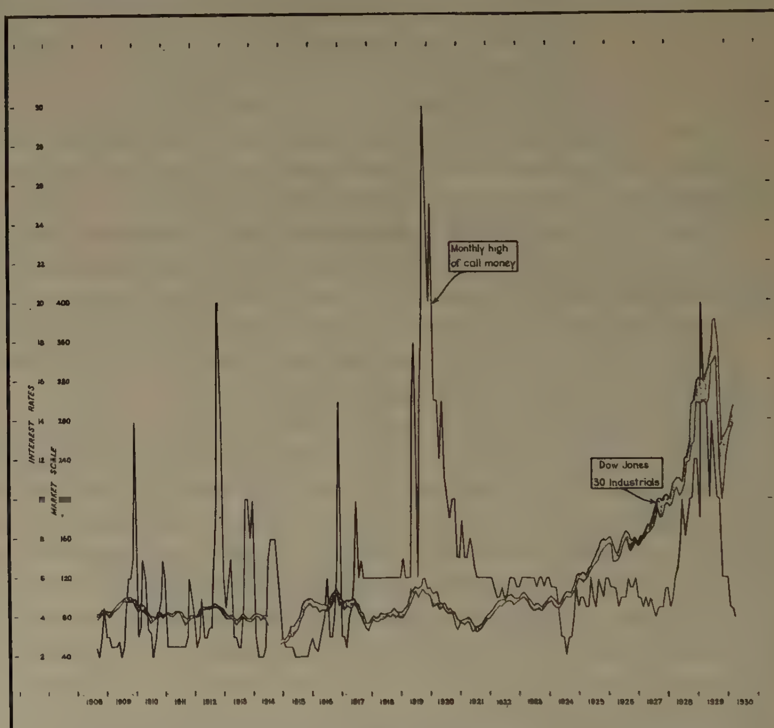

FIG. 1.—COMPARISON OF RATE OF CALL MONEY WITH STOCK MARKET AVERAGE OF PRICE.

Had the oil industry heeded the call money signal in July, 1928, and ceased all unnecessary fixation of money in physical property, the present outlook would be one of great prosperity. There would be no great potential production and little need for proration. There would not be such a large surplus of cracking capacity. Many retail stations with their background of trucks, tanks and tank cars would not be in existence. Since there is no probability that industry will ever correct the business cycle by preventing the credit climax, there is a great opportunity for any company that can develop the mental balance to deflate its position as credit tightens and expand to the fullest possible extent of inflation in the depth of national depression.

Gasoline, Its Relation to Petroleum Economics

By H. J. Struth,* Houston, Texas

(New York Meeting, February, 1931)

In these trying times of proration and low oil prices, it is decidedly necessary for all branches of the petroleum industry to accord full recognition to the economic phenomena that contribute to its varying state of welfare. Perhaps no other single factor has a more important bearing upon the general oil situation than the supply and demand of gasoline. Year after year, the records have shown that the degree of prosperity or depression accompanying the industry's developments has been to a large extent influenced by the degree of balance maintained between the supply and demand of gasoline. More and more it is being realized within the industry that equilibrium between the supply and demand of gasoline forms the basic structure of crude and product market values and, consequently, the deciding factor in the financial results of the industry as a whole.

The influence of the gasoline situation upon the market and financial structure of the petroleum industry was effectively demonstrated during 1930, when excess accumulation of gasoline undermined not only the refined oil market but the crude market as well. In fact, it was a top-heavy gasoline situation that defeated the realization of benefits that might have accrued from an otherwise favorable statistical position in the producing branch of the industry.

Indicative of this is the fact that crude oil production was curtailed to the extent of 98,323,000 bbl. last year, while refinery runs to stills were maintained at an excessive rate until late in the year, creating an excess gasoline production of 6,663,000 bbl. above actual requirements. Nevertheless, the movement to curtail refinery operations during the closing months of the year prevented a far worse situation, although it came too late to turn the ebbing momentum of the general oil market.

Despite the severe depression of the market values that accompanied 1930 developments, it can be said that the results attained during the closing months of the year, in the direction of production control, marked a decisive turn in the industry's economic affairs. In fact, a review of the oil situation from every angle points definitely to a better general understanding and recognition of the workings of the economic law of supply and demand. As a result, the year closed with crude production in

* Petroleum Economist, The Oil Weekly.

theoretical balance with market requirements, while refinery runs had been curtailed to the extent of reducing an earlier indicated excess of about 83,000,000 bbl. to an actual excess of but 16,000,000 bbl. The records of crude oil production in the United States point to an almost uninterrupted downward trend during 1930, having prescribed a decline from the beginning to the end of that year of about 575,000 bbl. daily. The evidence at hand also shows that refinery operations were conducted on a decidedly uneconomic basis. It is apparent, therefore that the responsibility for the unsatisfactory situation during 1930 rests almost solely with the refiner.

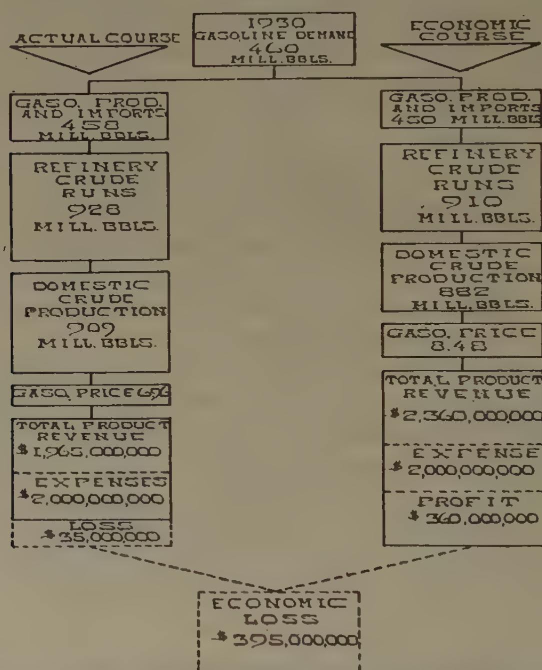

FIG. 1.—RELATIVE EFFECT OF ECONOMIC AND UNECONOMIC REFINING OPERATIONS IN 1930.

To effectively illustrate the relationship of gasoline supply and demand to the economic structure of the petroleum industry, the writer has constructed a graphic set-up (Fig. 1) depicting the relative effect of economic and uneconomic refining operations, having for its foundation the demand for gasoline. What actually happened last year is forcefully illustrated by the indicated loss of $35,000,000; what might have happened under a strict economic program is amply recorded by an unrealized profit of $360,000,000. The net result of the composite picture is an economic loss to the industry of $395,000,000. The foundation of the petroleum industry's economic and financial structure, therefore, rests

upon the demand for gasoline and the degree with which refiners exercise control over the supply of that product.

While gasoline represents about 42.5 per cent. of every barrel of crude refined, the revenue from the sale of this product constitutes 60.2 per cent. of the gross income of the refining branch of the industry. This is graphically illustrated in Fig. 2, which shows the approximate yield of products from a barrel of crude during 1930 and the proportionate revenue derived from product sales. Since gasoline represents not only the chief constituent of crude oil but also the chief source of revenue to the refiner, it is obvious to conclude that economic control of the entire oil industry

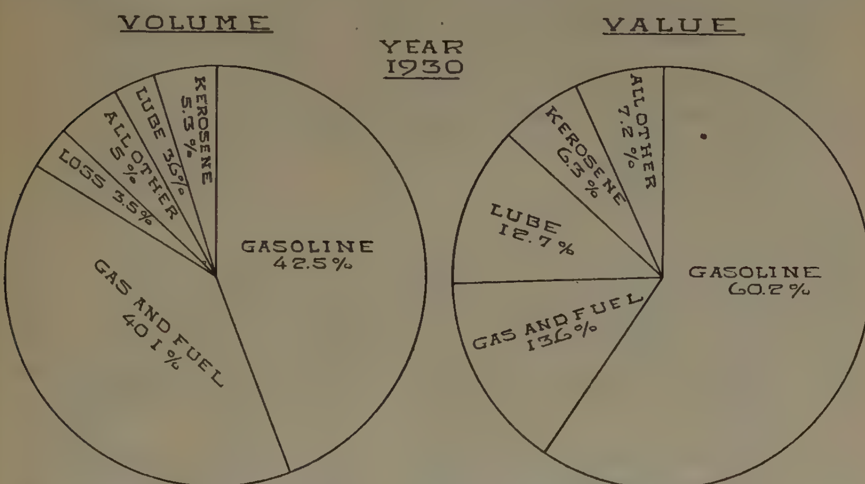

FIG. 2.—PERCENTAGE DIVISION OF A BARREL OF CRUDE IN PRODUCTS, BY VOLUME AND VALUE; YEAR 1930.

resolves itself, primarily, to control the gasoline supply. Therefore, any constructive program of oil production control must begin with a definite knowledge of anticipated gasoline demand. With that as a basis, the industry can intelligently project its operations on a sound basis that will prevent excessive processing of crude and, consequently, maintain a crude production level that will insure economic stability.

A careful survey of this year's gasoline requirements indicates that the total demand, including exports, will amount to about 478,345,00 bbl., a gain of 3.94 per cent. over 1930. Domestic consumption is not expected to exceed 408,056,000 bbl., a gain of only 3.18 per cent. over 1930, while exports are estimated at a total of 70,289,000 bbl., a gain of 7.65 per cent. over last year. Table 1 contains a summary of the factors to be considered in this year's gasoline outlook, as well as an indication of the probable crude required by United States refineries.

This year's gasoline demand forecast is based upon a probable average motor vehicle registration of 27,650,000, assuming that the total registra-

tion on Jan. 1, 1931, was about 26,800,000. On this basis, it is seen that refinery runs should not exceed 914,000,000 bbl. of crude this year, and of that quantity only 854,000,000 bbl. constitutes domestic crude, since about 60,000,000 bbl. of foreign crude will undoubtedly be run to stills.

Further analysis of the probable demand for gasoline during 1931 shows that about 346,435,000 bbl. will be consumed by motor vehicles in

TABLE 1.—*Preliminary Survey of* 1931 *Gasoline Demand and Crude Requirements*

	Thousands of Barrels
Domestic gasoline demand	408,056
Foreign gasoline demand	70,289
Total gasoline demand	478,345
Natural gasoline and benzol	58,000
Net gasoline from crude	420,345
Imported gasoline	*13,000
Net U. S. refinery gasoline demand	407,345
Crude required @ average yield of 44.5 per cent	914,000
Probable imports of crude	60,000
Domestic crude required by refineries	854,000
Crude exports and other consumption	31,000
Grand total domestic crude required	885,000

* Limit—if curtailment is applied in South America, as anticipated.

TABLE 2.—*Gasoline Demand*, 1931

Thousands of Barrels

	By Motor Vehicles	Miscellaneous Consumption	Exports	Total	Cumulative
January	20,982	4,012	5,882	30,876	30,876
February	21,347	3,814	5,217	30,378	61,254
March	26,125	4,488	6,529	37,142	98,396
April	27,112	4,993	6,177	38,282	136,678
May	31,268	5,720	5,338	42,326	179,004
June	32,358	5,834	6,034	44,226	223,230
July	33,760	5,918	7,590	47,268	270,498
August	34,020	6,034	7,212	47,266	317,764
September	32,644	5,609	7,138	45,391	363,155
October	29,658	5,272	4,343	39,273	402,428
November	28,643	5,020	3,979	37,642	440,070
December	28,518	4,907	4,850	38,275	478,345
Total	346,435	61,621	70,289	478,345	

the United States; 61,621,000 bbl. will constitute miscellaneous domestic consumption and 70,289,000 bbl. presumably will be diverted into foreign channels. Table 2 shows how this year's gasoline demand will probably be divided over each month of the year, as well as the cumulative course of consumption for all purposes. Carrying the analysis a step farther, Table 3 shows what in the writer's opinion should be a normal course of refinery operations for 1931, breaking the total gasoline demand into its component parts and expressing the net result in terms of crude runs to stills.

TABLE 3.—*Basis for Projecting Refinery Runs*, 1931

Thousands of Barrels

	Total Gasoline Demand	Imports, Natural Gasoline and Benzol	Net Gasoline from Crude	Course of Stocks[a]	Per Cent. Yield	Crude Runs Required	Daily Average
January	30,876	4,581	26,295	+3	42.87	68,334	2,204
February	30,378	4,507	25,871	+1.5	42.97	63,697	2,275
March	37,142	5,511	31,631	+3	43.53	79,556	2,566
April	38,282	5,680	32,602	− .5	43.59	73,645	2,455
May	42,326	6,280	36,046	−1.5	44.25	76,940	2,482
June	44,226	6,770	37,456	−2	44.36	79,927	2,664
July	47,268	6,819	40,449	−3	44.54	84,079	2,712
August	47,266	7,025	40,241	−3	44.62	83,462	2,692
September	45,391	6,321	39,070	−2	44.73	82,875	2,673
October	39,273	6,242	33,031	+1	44.76	76,029	2,453
November	37,642	5,585	32,057	+1	46.55	71,013	2,367
December	38,275	5,679	32,596	+2.5	47.23	74,308	2,397
Total	478,345	71,000	407,345	0	44.50	913,865	2,504

[a] Millions of barrels.

In order to illustrate fully the important function of gasoline in the economic structure of the petroleum industry, the writer has built up a complete itinerary of what he believes is a normal course for both refinery operations and domestic crude oil production this year. Table 4 shows how the demand for crude will probably be distributed on a monthly and quarterly basis, using as a foundation the normal refinery crude demand dictated by the demand for gasoline. The final step in this set-up, Table 5, is an allocation of the total crude demand to the various producing areas of the United States, and a suggested program of storage withdrawals, culminating in an economic crude production total and daily average for the respective regions.

It is obvious from the foregoing data that the demand for gasoline furnishes an ideal guide upon which to devise a well-rounded program of economic production control for the petroleum industry. As a matter of

TABLE 4.—*Basis for Figuring Domestic Crude Demand*, 1931

Thousands of Barrels

	Total Refinery Demand	Foreign Crude	Domestic Crude	Exports and Other	Total Domestic Crude Required	Daily Average	Quarterly
January	68,334	4,730	63,604	2,010	65,614	2,117	
February	63,697	4,339	59,358	2,025	61,383	2,192	2,268
March	79,556	4,868	74,688	2,499	77,187	2,490	
April	73,645	4,848	68,797	2,124	70,921	2,364	
May	76,940	5,089	71,851	2,435	74,286	2,396	2,451
June	79,927	5,147	74,780	3,072	77,852	2,595	
July	84,079	5,199	78,880	2,761	81,641	2,634	
August	83,462	5,376	78,086	3,072	81,158	2,618	2,640
September	82,875	5,231	77,644	2,447	80,091	2,670	
October	76,029	5,252	70,777	3,294	74,071	2,389	
November	71,013	5,021	65,992	2,762	68,754	2,292	2,334
December	74,308	4,900	69,408	2,499	71,907	2,320	
Total	913,865	60,000	853,865	31,000	884,865	2,424	
Daily	2,504	164	2,340	84	2,424		

fact, had such a program been pursued effectively last year, the industry undoubtedly would have made a far better showing. At any rate, the market structure would not have shown the decided reactionary trend illustrated in Fig. 3, which shows the course of the gasoline market in relation to the ratio of demand to supply and the posted price of crude oil.

If the efforts begun in the latter part of last year are continued throughout all of this year, the refining branch of the industry will

TABLE 5.—*Maximum Production Limit to Effect Normal Reduction in Crude Stocks*, 1931

	Indicated Total Demand	Daily Average	Desired Stock Reduction	New Production Required	Daily Average
Arkansas	21,170,000	58,000	635,000	20,535,000	56,000
California	213,525,000	585,000	13,129,000	200,396,000	549,000
Kansas	42,705,000	117,000	1,814,000	40,891,000	112,000
Louisiana	28,470,000	78,000	907,000	27,563,000	76,000
Oklahoma	198,925,000	545,000	9,308,000	189,617,000	519,000
Texas	288,455,000	790,000	5,443,000	283,012,000	775,000
Balance U. S.	91,615,000	251,000	3,629,000	87,986,000	241,000
Total	884,865,000	2,424,000	34,865,000	850,000,000	2,328,000

project a course of operations that will somewhat conform to the course suggested in Fig. 4. The solid line indicates the actual course of refinery still runs last year, while the broken line shows the rate at which crude should be run to stills this year, conforming to the indicated seasonal

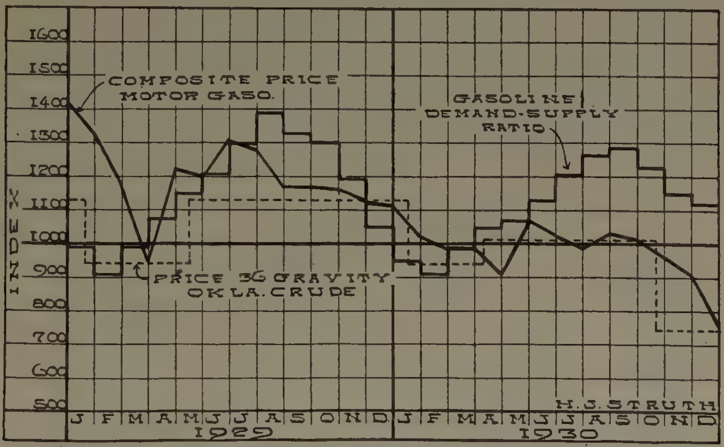

FIG. 3.—TREND OF GASOLINE PRICE IN RELATION TO ITS DEMAND-SUPPLY RATIO AND POSTED PRICE OF CRUDE.

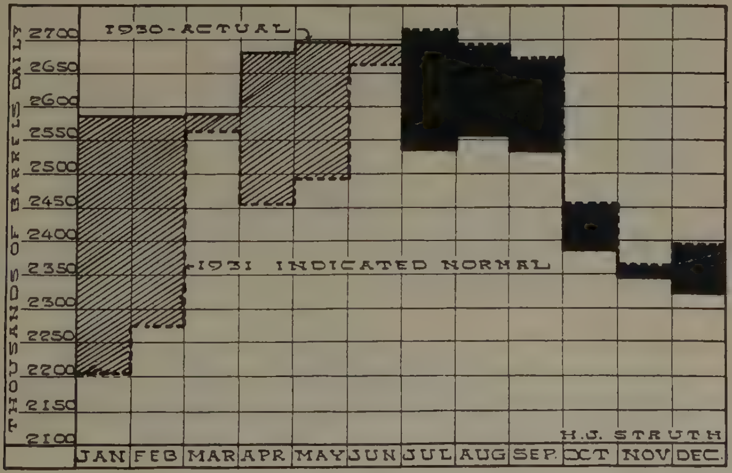

FIG. 4.—NORMAL COURSE OF CRUDE RUNS (DAILY AVERAGE) DURING 1931, COMPARED WITH ACTUAL COURSE DURING 1930.

Ribbed area shows extent of curtailment necessary during first half in order to attain justified gain during last half of year.

demand for gasoline. The shaded area shows how much runs to stills must be curtailed under the actual course of last year, while the solid black area indicates how much runs can exceed the curtailed operations of last year, provided that run schedules are not in excess of normal during the first six months.

That refiners have failed, miserably, in the past to maintain a normal supply of gasoline in storage is effectively shown in Fig. 5. In terms of gallons per motor vehicle, a normal stock of gasoline during the present year contemplates an average per registration of about 60 gal. Since 1921, there has been an indicated, necessary increase in the quantity of gasoline considered a normal reserve of from 46 gal. per vehicle to 62 gal. last year. In contrast with this is the actual course of gasoline stocks, ranging from 55 gal. in 1920 to a peak of 85 gal. in 1925. However, more attention has been given to this unwieldy situation since 1926, although the excesses of 1930 defeated previous efforts to reduce the abnormal

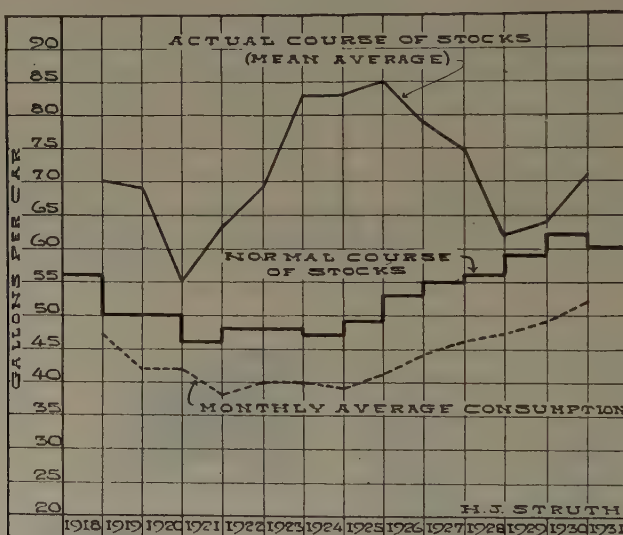

FIG. 5.—THEORETICAL NORMAL COURSE OF GASOLINE STOCKS COMPARED WITH ACTUAL COURSE (MEAN ACTUAL AVERAGE) AND TREND OF CONSUMPTION, EXPRESSED IN TERMS OF GALLONS PER MOTOR VEHICLE.

stored supply of gasoline. It is evident, though, that increased consumption per motor vehicle has also played a part in correcting the unsatisfactory state of the gasoline storage situation, as indicated by the curve of consumption and its direct effect upon the normal course of stocks.

On the assumption that an approximate normal gasoline stock per motor vehicle constitutes a ratio of 1.2, stock to consumption, the writer finds that the mean average stock of gasoline during 1931 should be about 40,000,000 bbl. In conformity with the indicated seasonal demand, this indicates a minimum stock, following the season of peak demand, of 34,000,000 bbl. and a maximum, as of about Apr. 1, of 47,000,000 bbl. In arriving at this conclusion it was assumed that 1928 was a near-normal year; at least to the extent where stocks per motor vehicle were only about

three gallons per car above normal, on an average. What this implied in the way of market returns during 1928 is evidenced by the fact that the price of U. S. motor gasoline averaged 9.15 ¢, whereas during 1930 the average had declined to but 6.96 ¢ per gallon. The difference in market values during those two years is attributed to the difference in mean average gasoline stocks per motor vehicle of about 9 gal., or a burden of roughly 6,000,000 barrels.

The cost of uneconomic practices in the refining branch of the industry during 1930 is portrayed in Fig. 1. What the effect was upon the industry as a whole is conclusively shown in Fig. 6, wherein the combined net profits of 10 integrated companies are charted, with the probable result projected for last year. Final statements of the financial results of 1930 are not as yet available, but there is sufficient evidence at hand to prove that net profits were sorely depressed during that period. In fact, on the basis of market values for crude and products, these 10 companies alone probably suffered a decline in total net profits of more than $200,000,000, producing a set-back comparable in many ways to that of 1927. One distressing factor in the financial situation of the oil industry last year was the necessity for evaluating excessive inventories at depressed market prices. These 10 companies alone no doubt were obliged to write off about $133,000,000 in inventory values, whereas it is conservatively estimated that the entire industry suffered a loss from shrunken inventory values of crude and products of not less than $222,000,000.

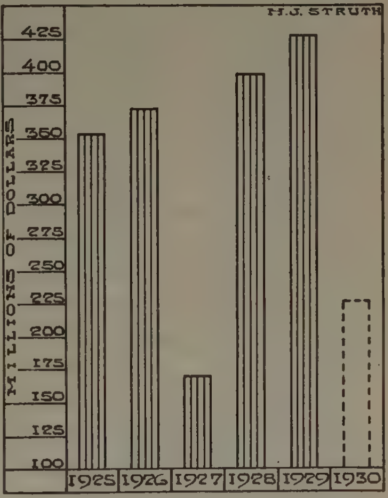

FIG. 6.—COMBINED NET PROFITS OF TEN INTEGRATED OIL COMPANIES, 1930 ESTIMATED ON BASIS OF INDICATED VALUE OF CRUDE AND REFINED OIL PRODUCTS, AS WELL AS PROVISION FOR INVENTORY WRITE-OFFS.

What the economic and financial outcome of the oil industry will be this year depends upon the degree of success attained in controlling producing and refining operations. One thing is certain, refiners as well as producers must conduct their operations along sound, economic lines. Unless effective measures of control are exercised throughout 1931, the industry cannot expect to recover the losses incurred last year. It is not the purpose of this paper to discuss the question of whether or not a tariff on imported oil would alleviate the distressing economic situation of the American oil industry, but it is obvious that control to be effective of results must include control of the supply brought in from

outside sources. In this connection, it will be noted that the writer included in his calculations a reasonable quantity of imported crude oil and gasoline. Obviously, every barrel of oil produced outside of the United States and added to the domestic supply dictates the necessity for restricting American production to the extent of such volume. Under present conditions, it is well for the industry in the United States to include with the economic supply of 1931, the quantities of foreign oil indicated herein.

It is also necessary that the industry consider the future effect of refinery expansion outside of the United States, since this trend plainly indicates the eventual dissipation of America's foreign oil markets. With the aggressive policies being pursued by foreign oil interests, there is a noticeable cessation in demand for American petroleum products. In fact, refineries now under construction in various parts of the world may bring about a further slackening in American oil exports this year than was apparent last year. It is believed, however, that the foreign demand for gasoline will continue to show an increase this year, perhaps to the extent indicated in Table 1. At any rate, the industry can afford to make allowances for foreign oil in its production program, as long as there is a balance in favor of the United States. When foreign demand recedes to the point where imports exceed exports, it will be necessary to completely bar such supply from consideration in American production schedules.

There is a distinct opportunity at hand now for the petroleum industry to effect a degree of stabilization that will invite more prosperous times for all concerned. That opportunity lies in a program of production control built upon a foundation of gasoline supply. Under the relationship that exists between gasoline supply and demand and the economic structure of the petroleum industry there is sound reason to expect refiners in every section of the country to maintain only a normal supply of gasoline on hand, along the lines suggested by the normal quantity of gasoline to be carried per motor vehicle. In order to carry out such a program there must follow a safe and sane course of refinery still runs and a consequent normal production of crude oil. Under such a plan of operation, it is possible for the industry to turn the tide from depression to prosperity. As it is, the industry has but another step to go to attain its objective; that step lies in the direction of a balanced supply of gasoline.

DISCUSSION

(*J. E. Pogue presiding*)

M. G. Cheney*, Coleman, Tex. (written discussion).—Experiences of the past year emphasize the need of some program of production control for the oil industry. Mr. Struth has thoughtfully attacked this problem and submits the thesis that since gaso-

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*President, Anzac Oil Corpn. and Monroe Production Co.

line represents 60 per cent. of the industry's income and its demand can be very closely estimated for months in advance, gasoline demand offers a good basis of production control, also that the fortunes of the oil industry largely rise and fall with the maintenance of balance in supply and demand of this, its main product.

Some years ago, with the advent of the cracking process some diagnosticians emphasized the increasing importance to the industry of the price of fuel oil. A year of industrial depression such as 1930 brings out the feature that whereas gasoline demand remains within a few per cent. of normal the demand for gas and fuel oils fluctuates by more than 25 per cent. from year to year. Since gas and fuel oils represent about 40 per cent. of the total refined market by volume, a change of 25 per cent. in gas and fuel oil demand means about 10 per cent. difference in crude demand. It might be argued from this basis that since the demand for gas and fuel oil is the main variable, it should be given first consideration in predicting future needs, hence that the volume of crude production and refinery runs should be held in line with industrial activity. Automobile registrations no longer record large annual percentage gains and the oil industry is becoming more and more sensitive to fluctuations in prevailing business conditions. Gas and fuel oils are subject to competition with other fuels; gasoline is not. Recent figures from the United States Department of Commerce are quoted to illustrate these relationships:

	October, 1928	October, 1929	October, 1930
Domestic gasoline consumption (1000 bbl.)...	30,696	33,238	32,267
Gas and fuel oil consumption (1000 bbl.) (approximate–production plus refinery stock decreases)............................	37,330	40,977	29,995
Employment, relative 1923–1925 average....	100	103	84

From this it appears that the demand for gas and fuel oils may fluctuate by 125,000,000 bbl. or more from year to year.

The producer has a far more difficult task in adjusting to decreasing demand than the refiner, because the former must meet drilling and offset requirements, prevent injury to wells and deal with many factors, some of which are outside his control. Hence distress selling of crude and gradual undermining of crude and refined prices is to be expected and is certain to develop in times of decreasing demand unless carefully guarded against. Judging by comparisons of crude prices the oil executives have been able during the past year largely to prevent distress selling of crude in California, while those of the Mid-Continent area for some reason or other were unable to do so. In Kansas, Oklahoma and North Texas the situation was aggravated by loss of market outlet by one of the main pipe line systems, which rather suddenly lost most of its market outlet and had to reduce takings accordingly.

Evidently unwise policies on the part of the refining, producing or crude purchasing branches of the industry may lead to general disorder. That a balance must be maintained between the supply and demand of gasoline cannot be denied, but other factors such as trend of business activity, gas and fuel oil demand, equalized outlet for crude oil production must be taken care of to insure prosperity in the oil business.

Economics of Distribution in the Oil Industry

By Sidney A. Swensrud,* Cleveland, Ohio.

(New York Meeting, February, 1931)

Much has been said and written about uneconomic and evil marketing practices in the oil industry, including such factors as loaning of equipment, price cutting and secret prices, commercial discounts, abuses of credit cards and coupon books, and so forth. It is not my purpose here to add to the discussion of those problems, but rather to attempt a discussion of some of the more basic factors in the general distribution economies of the industry.

The economics of distribution in the oil industry cannot be regarded apart from the general economics of the industry as a whole. The attempt to regard them as separate has led many people into the fallacy of believing that the responsibility for the apparent evils in the marketing end of the business lay entirely at the door of the marketing end. Such a view fails to take cognizance of many underlying factors; we can only expect to understand the distribution economics of the industry if we understand its general economics. We must realize also that the oil industry today is essentially the gasoline industry.

The oil industry may be said to have begun about 60 years ago. At the outset it was concerned chiefly with the manufacture and sale of kerosene, lubricating oils and greases. Gasoline was then a most obnoxious by-product. The early oil-marketing company was engaged almost exclusively in refining and marketing—it did not concern itself with production but bore the relation to it merely of a purchaser. It may be said that the urge of marketing development in those days, therefore, came from the refining and marketing end of the business. The raw material had not yet begun to exert its enormous pressure, nor had the producer of crude oil acquired a direct interest in the sale of the ultimate finished products.

Since then great changes have taken place. With the development of the automobile came a vast new demand for the raw material from which gasoline could be made. No longer could the refining and marketing companies be indifferent to the source of that raw material, particularly in view of the pessimistic outlook then presented as to the probable quantity of oil in existence. And despite the complete overturning of those early estimates, made before the bounty of nature and the skill of

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* Assistant to the President, Standard Oil Co. of Ohio.

geologists and mining engineers had revealed themselves in undreamed of reserves of crude oil, the motive of the large marketer to integrate back to the crude still constitutes a strong force. The need of uniform and assured quality, made the more necessary by intensive advertising, tends to force him into refining. Then it may seem expedient for him to secure production in order to protect his refining and marketing position, although often he is merely attracted by the hope of reaping a profit on the raw material for which the sale of his finished product and his refining position give him a justifiable use.

The production of crude, however, was not in the beginning and never has been confined to refining and marketing companies. Many companies began at the production end. The abundance of crude of which many of these companies found themselves possessed has in turn however exerted upon them a powerful pressure to engage in refining and marketing activities in order to obtain for their production a more assured outlet. It is sometimes difficult or impossible to sell crude oil as such, but there is almost always a possibility of selling gasoline, at some price. So the producer of crude becomes a refiner; then, as he still finds it difficult to dispose of all his gasoline at wholesale for a decent price, he tends to push on into the retail marketing end in order to obtain that final utopia of assured outlets.

Completeness of Integration

With the exception of a few isolated products, such as milk or ice, perhaps, there is scarcely a parallel to the oil industry in the completeness of integration on the part of its major representatives. Aside from the other commodities mentioned, where is there an industry in which so large a percentage of its members produce the primary raw material, manufacture the finished product, and sell so large a part of that product to the final consumer at their own retail stores?

These forces, which promote this integration from both ends of the line, probably would not be so effective were not the natural conditions more propitious than in most industries. Consider the facts: Gasoline and oil constitute the chief products sold at a service station, and, in fact, their sale alone constitutes a full-time retail activity. These products can be made by a single refining organization from a single raw material, crude oil, and that raw material can be produced by the same company with an investment that need not be out of proportion to the business as a whole.

These rather singular facts about the oil business may seem more interesting than significant, and yet they help to explain other facts. The participation of practically every large company in the industry in all of the ends of the business—production, refining and marketing—

provides a continuous ownership of the product from the first moment the raw material gushes from the earth to the time when the finished product is sold; it provides, therefore, a direct conduit for the pressure of that raw material upon the final market.

Channels of Distribution

Even today, of course, the greater part of the gasoline sold at retail is distributed through dealers rather than through company-operated service stations, but these dealers operate usually on a definitely fixed and assured margin, and in most sections of the country they usually sell the branded oil products of a single company, most often through the company's own equipment so far as pumps and tanks are concerned. These dealers therefore resemble commission agents rather than independent retailers buying in a wholesale market and bearing the ordinary risks of business. As a matter of fact, they are being set up more and more on an actual commission agency basis. The remaining form of retail distribution of gasoline and motor oil is through the so-called independent jobbers, who actually buy their gasoline at wholesale in tank cars, some buying from companies whose brands they use, some buying from varying sources and using usually their own brand names.

It is one of the anomalies of the oil industry that the same company may be selling its products through all three of these channels of distribution, even in the same territory—indeed, it is a fair statement to say that this is the common practice of most large companies in the industry. In studying the marketing practices of most businesses much emphasis is placed upon *which* channel of distribution a manufacturer should choose—whether he should sell through wholesalers, direct to the retailer, through chain stores, or set up his own retail outlets. Usually he considers that he must choose one of these methods to the exclusion of the others; it is rare indeed that he decides in favor of them all, or that he could do so with any degree of success, or any lack of mutiny. Monogamy in marketing is the rule of most industries, but polygamy reigns in ours.

The explanation of this situation probably lies in several facts. The gasoline industry is relatively new; but the distribution of gasoline had been preceded by a widespread system on the part of oil companies of tank wagon distribution of kerosene and oil to farmers, dealers and commercial users. This system simply took on gasoline, and no new retail establishments were set up at the start. The earliest real business called into being by the automobile was the garage, for the mechanical difficulties presented a more important problem at the start than securing the small quantity of fuel necessary for the car's operation. The garage operator therefore became the first retail source of supply for gasoline, aside from the oil company's truck.

Then several things began to happen. The requirements for gasoline and oil grew rapidly; supplying them to the motorist became a full-time activity which would support a retail establishment, and so numerous men began to set up in the business. The public liked this because they got better service; there was more room and they did not have to wait until the garage mechanic could finally be located and induced to leave his repairing long enough to wait on the gasoline trade. The large oil companies perceived that a separate retail establishment to sell gasoline had real merit and met with public approval, and so gradually they began to set up stations of their own. This did not meet with the resistance from existing dealers which probably would have been the case in an older industry, because the demand was increasing faster than the outlets and no one felt that he was being ruined. As quality of service and of products became more and more important the oil companies went more and more into the operation of their own stations. But they did not give up the dealer outlets, because, in the first place, many of these dealers were necessary to give them distribution at points where the gallonage would not warrant operating their own service station; in the second place, the demand was still increasing so fast that both types of outlets were profitable and it would have been difficult for oil companies to build enough stations to keep up with it; and finally, because in the meantime the supply of crude oil had begun to press upon the market; more and more oil companies were going into the marketing end; they needed distribution and the easiest way to secure it at a reasonable expenditure of capital was through dealers. Hence, instead of being forced out, the dealer became a more coveted prize than ever, so long as he could dispose of a few gallons of gasoline a month. If he showed no eagerness to take on a new company's goods, he could be persuaded by more generous margins or the promise of being supplied with a more modern array of pumps, tanks, air compressors, paint for his buildings, and the like.

Price Margins

As this latter factor became more and more important with the increasing pressure of crude, margins began to grow wider. At the beginning the price to a dealer was as low as 1¢ per gallon under the retail price. Few dealers, of course, at that time relied entirely upon gasoline and oil for their revenue, but usually carried them as a side line to their main business, as a repair shop or a general store. With the competition of oil companies for immediate outlets this margin grew until it reached 3¢ and even 4¢ or more per gallon, and of course many people were induced to set up full-time service stations and become dealers. Partly as a means of preventing substitution of goods, and partly to promote the oil company's brand names, but chiefly to give the dealer an added induce-

ment, the practice of "loaning" the dealer pumps and tanks grew until it has become all but universal in the industry.

The only limiting factors on the width to which the dealer margin is pushed would seem to be: (1) the amount which obviously exceeds that for which the oil company could operate its own retail outlet; and (2) the amount of the margin which the dealer will keep rather than give away to his customers in an effort to increase sales. This latter factor is the more effective, for the practice of price cutting on the part of the dealer immediately begins to affect the gallonage at the companies' own service stations, so that to protect their business they are forced to reduce the spread between the price to the dealer and their own retail price.

The margin which the dealer will not cut appears to vary with time and place, and the seasons. He seems less inclined to keep it all at the present time, when outlets are multiplying faster than business is increasing, than when the reverse was true.

But not all oil-refining companies can readily secure retail or dealer distribution, or enough of it, to take care of their total refining capacity or their supply of crude, so there has grown up also a wholesale market for gasoline in tank-car lots. As the quantity of gasoline thus available began increasing rapidly as a result of flush crude production, the price of both gasoline and crude oil were falling. In 1920 crude sold for $3.50 per barrel at the well, now it sells for less than one dollar. The retail price of any commodity, however, tends to lag behind the wholesale price, and this was true in the gasoline business. It was particularly true so long as the retail distribution of gasoline was so largely carried on by company-owned service stations and dealers operating on a fixed margin.

The Wholesale Buyer

The entry into the field of gasoline retailing of the actual wholesale buyer who could take advantage of the wide spread between wholesale and retail prices probably was delayed somewhat by two factors—one the seeming mystery which surrounded the industry and the apparently traditional belief that disaster awaited anyone who crossed the purposes of the large oil companies, the other the necessity for special tanks, pumps, etc., for warehousing and tank wagons or tank trucks for delivery. In other words, the retailer who would buy gasoline at wholesale needed a considerable investment in unusual types of capital. These facts simply meant that for a time the fundamental factors of supply and demand did not have a very direct opportunity to exert their force immediately on the retail prices of gasoline in relation to wholesale prices. The result of this delayed adjustment of retail prices to declining wholesale and crude oil prices was, of course, a tendency for the margin between wholesale and retail to be abnormally wide.

The opportunity of the wholesale buyer to capitalize such a situation soon became apparent, and he thrived mightily, especially as the difficulties anticipated turned out to be less real than apparent. He, like the dealer with the too wide margin, was tempted to cut the price either openly or secretly in order to increase his volume and his total profit—and this tendency was accentuated by the fact that frequently he had no well-known brand name to aid his sales, neither had he, in general, developed as high a quality of service as the company that had been longer established.

The leaders of the oil industry might possibly be criticized for their apparent shortsightedness in postponing the decline in retail prices and thus fostering the development of a vast array of competitive marketing organizations attracted merely by the wide margins between wholesale and retail prices. Indeed, such a criticism seems pertinent—perhaps it may even be made today in some instances—but in the main we must regard it as the general working out of economic forces hampered slightly perhaps by the human inability to perceive the direction and effect of those forces, in the eagerness for immediate profits.

It is one of the ironies of most new businesses having a rapidly expanding market that the high rate of profit in the early stages causes a rush of new capital into them, which does not cease until long after the reasonable needs of new capital on which a fair return could be earned have been met. Witness two recent examples—airplanes and radios.

Particular Phases of Distribution

The attempt thus far has been to trace certain of the developments of the industry and to interpret and account for these developments in terms of their apparent causes. It is not difficult to see that behind almost all of the unusual facts lies the pressure of crude oil for an outlet. Not everyone understands as clearly as a petroleum engineer probably does how not only natural law and engineering skill but the man-made laws of the land have contributed to that plethora and pressure of crude oil.

It remains to analyze a little further some of the more particular economic phases of the distribution end which we may enumerate under the headings of prices, margins and costs, the effect of brands, quality and advertising, and merchandising trends.

Prices

For few commodities probably are prices less understood than for gasoline. Legislators and editors frequently feel that laws should be passed about them, apparently on the general theory that what is a mystery to them ought to be dealt with by law. People express great

amazement that the price of gasoline at one point should differ sharply from that at a near-by point. Likewise, they see something mysterious if not sinister when practically all major companies raise or lower their posted prices simultaneously. Beneath these surface indications regarding price are some simple and some rather complicated economic factors.

The general level of gasoline price is fundamentally determined by the interaction of gasoline demand and crude oil supply. In a very narrow and short-term sense, the price of gasoline reacts to the supply and demand factors for gasoline alone, but in our industry the rapidity with which crude oil can be converted into gasoline makes the supply of crude the dominant factor. The facts bear out this statement, for over a period of the last 12 years there never has been a major change in the trend of wholesale gasoline prices that was not followed shortly by a change in the same direction in crude oil. The statement just made that changes in crude oil prices *follow* changes in wholesale gasoline prices is a true statement of the actual sequence. It is a logical sequence because the wholesale gasoline market is an extremely sensitive one, whereas the market for crude oil is rather sluggish, owing to the physical necessity, in general, of pipe line connections with a specific buyer. It is not a market in which buyers and sellers can meet openly on equal terms and engage in that "higgling and bargaining" which are the essentials of a market in which the forces of supply and demand can rapidly and continuously be balanced in terms of price. This simply means that the wholesale gasoline price, being more sensitive, tends to reflect sooner those supply and demand factors to which the price of crude must later respond.

The retail price of gasoline, as has been mentioned, tends to lag behind the wholesale price because there is less higgling and bargaining by the retail buyer, and perhaps also because the inconvenience of fractional cent retail prices tends to cause a postponement of retail price changes until enough change in wholesale prices has accumulated to warrant a change of convenient amount in the retail price.

The close correspondence of retail gasoline prices and price changes among leading companies is the result of economic necessity and not of collusion. The commodity gasoline, to be sure, is bought to a considerable extent on the basis of brand, but the normally small differences in quality which usually have existed between the products of good companies and the difficulty of readily apprehending the differences in a motor car, have made the customer, as a general rule, unwilling to pay more for his preferred brand than for the comparable brand of another company. Suppose therefore that today a certain leading marketer cuts the price two cents. No other representative company could afford not to cut, unless it were willing to risk losing much of its business. Likewise, on the up-side, a leading company raises its price, say, one or two cents. In this case, if its competitors do not follow its

lead it would have no option but to reduce its price back to their level or lose business. These factors practically compel all companies having reasonably comparable products and service to sell at the same retail price—the same thing is true of most other products we buy, with this difference, however: A large portion of the public buys gasoline frequently; those buyers are mobile—being in their automobiles they can readily drive a little out of their way if any price advantage makes that desirable. Then, too, gasoline is the principal product sold at a gasoline station and prices usually are posted very conspicuously, especially if they are lower than the prevailing level, so that the opportunities for price comparison by the customers are almost unparalleled. These factors simply narrow down the time limit the various companies have in which to adjust their prices to prevailing levels and any oil marketer knows that if a cut price is suddenly posted by a near-by competitor he begins to suffer serious and *immediate* loss of gallonage. The result is what may be called a follow-the-leader price custom among gasoline companies marketing on a comparable basis. Obviously, no price increase could be effective without the support of the company with the greatest representation—it tends to become a custom, therefore, for the company with the greatest distribution to be the leader in posting price changes in that territory and for other companies to follow those changes almost instantly, so long as they seem reasonably sound, with no need of agreements or collusion.

It must not be inferred from this that any company, large or small, has any power to establish or maintain prices that are not sound. No company in any competitive industry can do more in effect than to nominate a price. If that price receives the customers' dollar votes it is elected; but if it is too high and some other marketer, who feels he can operate more profitably on a smaller margin and greater volume, nominates a lower price and the public casts its dollar votes for that price, then the lower price is elected. The ballots are counted every hour of the day.

Margins

In any competitive industry, likewise, the margin between the delivered cost and the retail price will never for long be much more than the typical cost of marketing through the existing channels of retail distribution. Whenever the posted price exceeds the delivered cost by more than this typical marketing cost, either that posted price will have to be reduced or it will be nullified by commercial discounts, secret rebates or miscellaneous open price cuts by independent jobbers. The variations in the method are many, but the effect of all is the same; namely, a reduction in the effective prices realized. One that is particularly noticeable at the present time in many sections is the so-called tank-car service station. The promoter of this type of outlet usually gets a location at the

juncture of a railroad and a good traffic artery and puts up a station, usually an inexpensive one, with enough storage capacity to receive deliveries in tank cars. He buys his gasoline directly from a refiner—usually one who has no other marketing interest in that territory and who has excess gasoline to dispose of. With this set-up the promoter begins business, usually at a price from 1 to 3 ¢ below the prevailing posted level. If, as frequently happens, he gets a good gallonage, he enjoys some success, for even though his margin is small his expense of distribution per unit is also small. He captalizes at once the overexpanded marketing condition of the industry which has made for a wide margin, and the immediate oversupply of gasoline which enables him to buy cheaply. Not infrequently, also, he poses as a friend of the people who will protect their interests by giving them lower prices. When such a marketer is successful in obtaining a large gallonage the companies adversely affected usually meet his prices; then, of course, his business fades, for it does not rest primarily upon giving service, convenience, or uniformly high quality, but chiefly upon price.

How shall we regard this type of marketer? In so far as he does not dilute his product, give short measure, or evade the gasoline tax, he seems to be an inevitable part of the system. He is like the arbitrager of foreign exchange. When the margin between two foreign exchanges begins to widen this arbitrager steps in and takes a profit by buying in one exchange and covering in another. When the margin gets too wide the importer decides to make actual gold shipments and this tends to eliminate the discrepancy. So with the price cutter, when the margin between wholesale cost and retail price becomes too large, he steps in and takes a profit at a cut price and the very fact that he does so tends to bring the margin back to its economic level.

In part, also, he challenges the validity of the ordinary method and cost of marketing gasoline with its resulting wide margin per gallon. Obviously it is cheaper to sell gasoline in large quantities at one location than in small quantities at a dozen locations. How much extra expense for the latter type of distribution is economical will depend entirely upon how much more the public will be willing to pay for the extra convenience of buying its gasoline at scattered convenient locations than at a few centralized points. Most customers undoubtedly will be willing to pay something more, for gasoline has become a convenience goods and the customer's very ability to go far out of his way to buy gasoline is sometimes conditioned by the danger of running out in the meantime.

The evidence of actual experience would seem to indicate that relatively few customers will sacrifice much in the way of convenience, quality or service for a saving of one cent per gallon, but that when the difference begins to be as great as two cents or more their affections are far less secure.

Marketing Costs

Marketing cost, therefore, undoubtedly will become increasingly important. The pressure of crude is forcing more and more companies to push their products upon the market at constantly increasing costs. At the same time, the opportunity of obtaining a wide margin between delivered cost and retail price is being constantly circumscribed by price cutting, some of which has a basis in lower marketing expense.

The author recently made some comparisons of the costs of marketing at retail service stations with those in other retail lines. The figures indicate that the cost of retailing in the petroleum business probably exceeds that of most other ordinary retail trades. The cost of rent in the service station business, as a percentage of sales made, easily exceeds that of jewelry stores, and is more than double that of department stores. A station, to get any considerable gallonage, ordinarily must be located on a good traffic street, and it must have a good frontage on the street, together with attractive and convenient facilities. That frontage is expensive, and so are the facilities, but this does not deter other competitors, eager for gallonage, and so they build stations also, with a consequent dilution of the average gallonage for all stations and a resulting high cost per gallon of marketing.

The expense per gallon at a service station increases rapidly as the gallonage decreases, for a large part of the expense is fixed and even the largest of the variable items, salaries, cannot usually be reduced in proportion to a serious decline in sales. Since the *margin* per gallon is practically constant as between stations of different volume, it can readily be seen that the reduction in profit is entirely out of proportion to the reduction in sales. Actual computations show, for instance, that if the sales at a salary-operated station, doing, say, 12,000 gal. per month, are reduced by 33 per cent., the reduction in marketing profit is about 80 per cent.—or to reverse the illustration, if at a salary-operated station, sales of 8000 gal. could be increased to 12,000 gal., the marketing profit would be increased about five times. The seriousness of dilution in its effect upon expense and profits therefore can be readily appreciated. In view of such a situation it is not strange that each company should do its utmost to secure a greater share of the business through its outlets by means of improved products, effective advertising of its brands and better service.

Brands, Quality and Advertising

It is usually accepted that there is nothing the oil marketer can do materially to affect the total gasoline consumption. His only hope is to secure a greater proportion of the existing demand. He can attempt to secure it through the negative device of cut prices, but that will avail him

little, for his competitors will follow him within a few hours and neutralize his advantage. He can advertise his products and his service more widely without improving them, or he can improve his products or his service without advertising them—neither device will be fully effective without the other. He must therefore try to do both.

Not long ago the author listened to a conversation between an oil marketer and a banker. The oil man was talking about differences in quality of gasoline and when he had finished the banker said, "Why, you speak as if these differences were real!" Today certainly no one in the oil industry will deny that they are becoming increasingly real, or that the public with its modern motor car can long be oblivious to the reality of the differences. This is particularly true as regards the antiknock quality of gasoline. The former qualities that were stressed—gravity, color, end point—did not have much significance to the automobile driver, but not so with antiknock. Differences in motor oil likewise are becoming better recognized, and there is no doubt that the public is already keenly alert to the quality of service.

If these things are true we may expect the public to become more and more brand conscious. We may expect to see more difficulty encountered by the dealer who has no well advertised high-quality brands, and more price cutting on his part as a result. We may certainly expect to see more money spent in improving quality, in advertising and in service station facilities. And these factors mean a general stepping up of the "ante" all the way along the line.

We have there all the appearance of another of those "vicious circles" that long since earned for economics the reputation of being "the dismal science." First we see expenses increased because of the general dilution of outlets; then we see them further increased by the attempt of each company to increase or at least maintain the gallonage of its own particular outlets.

Merchandising Trends

Such a vicious circle, however, has its tangents. At every revolution some of the weaker contestants drop out, although others with new capital often step in. At the same time new practices are evolved to check the cumulative effect of the vicious circle, and the beginnings of one such factor probably are evident in the growing tendency among oil companies to take on other lines of merchandise which can be sold at service stations, such as tires, batteries and miscellaneous supplies.

We must interpret this in its broadest sense as an attempt to reduce the effective cost of marketing gasoline and oil by securing some extra revenue to help carry the increasing expense load and take the place of the decline in revenue from a diluted volume of oil and gasoline sold on a narrower gross margin. Some people may say that it is simply

because additional profit can be made from selling these other lines. Whatever the motive may be, the important question is whether this development is economically sound. The author is inclined to think that it may be, because if properly handled various products related to automobile use probably can be distributed through existing service stations with relatively little increase in selling expense. This probably is not true of the tire company, which in order to take on gasoline and oil must build a *new* service station and incur much extra expense, and its own product, if the station is successful, is bound to become a secondary source of revenue. The average motorist spends at least 10 times as much on gasoline, oil and lubrication as he does on tires. In other words, gasoline cannot be sold effectively by *existing* tire outlets; new outlets primarily designed to sell gasoline must be created before the tire company can go into the gasoline business effectively. It seems a sound economic principle that any commodity in the long run will tend to be sold through the medium that combines the greatest degree of economy in distribution with convenience to the customer. For a number of products, existing service stations provide this combination. And it may be that eventually it will become apparent that the selling of gasoline and oil alone no longer constitutes an economical retail operation. At present we can only speculate upon the question or upon the possible trends which any developments might take, having as their motivating purpose either the increasing of existing profits or the reduction of the effective cost of marketing gasoline. Certain it is, however, that additional lines of products or activities will bring with them more complicated merchandising problems and put that much greater strain on the marketer's qualifications.

Summary

We may summarize the economics of gasoline marketing by reiterating that through it all the motivating force of crude oil pressing for a market can be seen. We have watched the mechanism for the exertion of that pressure develop from the stage when the pressure was relatively indirect, because production was not linked with refining and marketing,—to the present stage when a high degree of integration has made for an exceedingly direct conduit of the pressure, and when in addition the jobber and the tank-car service station have been developed to a point where they quickly adjust any unduly wide margins between delivered cost and retail prices.

We see the pressure for sales of gasoline breaking out in increased outlets, in various forms of price cutting and in increased marketing costs. With the growing integration of oil companies, more and more of the profits of other ends of the business are, the author believes, being pushed over into the marketing end, to be used there in the struggle for outlets.

It does not seem unlikely that we shall see much of the excess capital, which has been so prodigally poured into the industry, dissipated finally on the marketing battlefield. We can discern therein, however, no departure from the economic law of the competitive system, for it is a struggle for the survival of the fittest. In that struggle the possession or command of capital will be important, but it will be less important than sound merchandising—the essentials of which are quality products, superior service, intelligent price policies, effective advertising and economical operation.

Stabilization of the Petroleum Industry

By Leonard Logan,* Norman, Okla.

(New York Meeting, February, 1931)

The petroleum industry is not peculiar in that it has a problem of stabilization. Economic conditions, not only in the United States but throughout the entire world, are unstable. However, the petroleum industry together with coal mining and agriculture has experienced a longer period of depression than most of the others. It is significant to note that industries engaged in the production of basic raw materials, the primary industries, have not enjoyed as much prosperity since the war as the secondary industries, or those engaged in the fabricating of raw materials and their distribution.

The problems of the primary industries are not all the same. Overproduction has existed for several years in agriculture but its causes are not the same as those that have brought about overproduction in the petroleum industry. Unlike agriculture, the institution of property rights and the migratory nature of oil are responsible for the oil man's troubles. Our laws permit the owner of the oil and gas rights, with certain exceptions, to drill when and where he pleases. Since oil is migratory, the adjacent property owner must go and do likewise—drill. This condition spread over a wide area soon brings to the surface more petroleum than can be readily absorbed by the market, creating a condition of overproduction.

It is significant to note at this place that when overproduction occurs the complete units in the industry suffer least. A complete unit is taken here to mean a corporation engaged in all the phases of the industry through production, transportation, refining and marketing. In the present depression the complete units in the industry are not in as bad financial condition as those engaged in single phases of the industry. The same thing can be said of the zinc industry, the lumber industry, and the other industries where there are organizations engaged in all the steps through the production of raw materials to the marketing of the finished product. The reason for this is that the complete units are in better position to coordinate all the factors that would work for a stabilized condition than are the units that are engaged in a single branch of the industry.

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Stabilization and Plans for Attaining It

Modern economic theory is very different from that of the earlier economists. To earlier economists the ideal state of an economic society was one that was in perfect balance; under ideal conditions the forces of supply and demand would interact on each other and result in equilibrium. Modern economists look upon economic life as a flow, a stream of transactions, so to speak, not as a vast lake whose surface seeks tranquillity. Their goal is to control the flow so that it may progress in an even manner. Stabilization means a controlled flow of business transactions, either through voluntary or involuntary methods, in order that the business man may more easily visualize the future. Industrial history shows that at no time have conditions been ideal; never has there been a state of complete equilibrium nor a time when the flow has been even and perfect. The petroleum industry is no exception. Since its foundation in 1859 to the present day there have been recurring periods of overproduction.

Industry today is dominated by the profit motive. For an industry to survive, it is necessary that it earn sufficient profits to enable those in the business to continue. Stabilization does not mean the control of prices, nor does it mean the guarantee of profits to the marginal operators. Stabilization of the petroleum industry today means the withholding of sufficient quantities of oil so that the values of the products when costs are deducted will leave a reasonable profit to the industry as a whole. A reasonable profit is here taken to mean a profit that will enable those now in the business to continue their activities. At the present time the problem of stabilization is the control of supply, not to obtain exorbitant prices, but to insure a reasonable profit to the industry as a whole on the capital invested.

Curtailment of crude oil production and the manufacture of gasoline is the most pressing problem confronting the petroleum industry today. This was adequately and sufficiently brought out in the report of the Committee on Petroleum Economics to the Federal Oil Conservation Board last November. Three major plans have been proposed to curtail the supply of crude oil: unit operation, proration and a tariff on imports of petroleum and petroleum products.

Unit Operation and Proration

The details of unit operation are familiar to most of those in the oil industry and since it is not extensive in its application in this country no time will be consumed here in elaborating on the merits of the plans and the possibilities of putting them into general operation. Although at the present time, with the exception of Kettleman Hills, there seems to be little progress made to expand unit operation in the various fields

it is a goal worthy of its purpose and the industry should not relax in its efforts to bring unit operation into more general practice. Unit operation is the soundest plan both from an engineering and economic standpoint presented thus far.

The most effective device employed to date for the curtailment of production is proration. This plan was first put into operation in Oklahoma and has been most successful in that state. However, the Committee on Petroleum Economics was correct when it stated in its report[1] that "curtailment of current supply is in the nature of an emergency measure, and should not be expected to provide a cure for the fundamental economic maladjustments existing in the petroleum industry which arise from the circumstance that this activity is overdeveloped, overcapitalized, and rests upon an unsound method of competitive offset drilling. Curtailment of production alone cannot remedy these conditions."

At best, proration is only a temporary measure inaugurated to meet an emergency. Proration as now applied does not rest upon a sufficient scientific basis to insure its permanency. Until the emergency has passed, however, it would be unwise to abandon it. The old adage that "it is unwise to trade horses in the middle of a stream" holds good in this instance.

Proration plans in Oklahoma in recent weeks have been the object of severe attacks. Those who have attempted to break proration may be divided into two classes: (1) Those who are motivated by selfish interests and (2) those who are guided by false economics and misguided ideals.

Arguments against Proration

Some of the arguments advanced against proration are so naïve they merit no consideration.

An argument frequently heard is that proration should be lifted and let the law of supply and demand take its course. The statement may appear to be rank heresy, but there is no such thing as a law of supply and demand. What is often called the law of supply and demand is only a formula. Indeed, there are certain forces that create demand and other forces that create supply but these forces are not subject to specific laws. The things that create supply or demand for a specific commodity or service may not be the same for another, or for the same commodity or service at another time and place.

The demand for petroleum and its products is fairly inelastic. This point was demonstrated in the report of the Committee on Petroleum Economics.[2] According to Farish, in a statement to the press released Jan. 4, 1931, the consumption of gasoline for 1930 showed an increase of

[1] Report of the Committee on Petroleum Economics to the Federal Oil Conservation Board, Nov. 6, 1930. Special Bulletin, Amer. Petr. Inst. (Nov. 18, 1930) 3.

[2] *Idem*, 4.

5 per cent. over 1929 in spite of the general depression in industry. The Committee of Petroleum Economics stated that in the absence of a basis for precision the estimated demand for gasoline would range from a decrease in 4 per cent. to an increase of 4 per cent. A demand that will fluctuate within this narrow range can be considered very inelastic.

Now, if the proration lid were lifted and production were permitted to carry on unrestrained it would not result in the increased consumption of petroleum products because of the lowered prices, even assuming that it could be done at a profit, but it would result in flooding the market with oil until it would bankrupt every small operator in the industry.

It is also maintained that proration is the cause of the present demoralized conditions in the industry. The reverse is true. If proration had not restricted the flood of oil on the market, conditions would have been so bad that the industry would have taken years to recover.

The charge is made that proration is encouraged in order to permit importing companies to bring in cheap oil from abroad. This charge cannot be substantiated. However, there is a moral obligation on the part of the companies that have production abroad to restrict their imports accordingly. This, I understand, some of the companies are doing.

Some companies maintain that they are prevented by proration from running their own oil to their own refineries when they have a market to absorb their products. Assuming this to be true, it must be remembered that in a program of this kind no favoritism can be shown. If one is permitted to run oil unrestrained, all should be given the same privilege. If all the operators exercised this privilege the existing market would be undermined. The demand for petroleum, as described above, is inelastic and to increase the supply would not increase the amount consumed. Proration is a cooperative program and all those directly interested should participate in the program. All should share the disadvantages proportionately and if there are market advantages these should be shared proportionately likewise.

It is argued that some independent companies with production must buy oil to meet their own refinery needs because of proration and at the same time sell at a loss the refined products at a low price. It is always better to assume a small loss than a large one. If refining companies were permitted to run all the oil out of flush production fields to meet the capacities of their plants, those not having refinery connections should be granted the same privilege to run oil unrestrained. If this condition were permitted the industry would become so demoralized that the refining companies would have been better off had they never had any oil.

It has been charged that proration is at the behest of monopoly and monopolistic influence. By this time, individuals both within and without the industry should know that the industry is anything but

monopolistic. It is one of the most competitive in American industrial life today. It is the competitive conditions rather than monopolistic powers that make proration necessary. The industry is suffering from too much competition. It is not denied that large units in any business have more influence on the market than do the small ones. In any industry where there are large units the business is on a follow-the-leader basis. Instead of proration being perpetrated to destroy the independent producer, it is his very salvation. Besides, industrial leaders of large enterprises today prefer the presence of a large number of independents. If the independents were put out of business it would subject the large integrated companies to more governmental scrutiny and investigation, and to be exposed in this light is not desired by any one regardless of how blameless the business may be.

It is also charged that proration is an attempt to obtain control of oil fields by large companies. Why should large companies desire control of the fields when they have now as much oil in storage as they care to hold in the face of a still larger potential production? Large companies are now and will always be interested in a permanent source of supply. Large companies, like the small ones, are in the business to make money. They are not concerned in driving out the small independent. There is no economic justification in the argument that they desire to control the oil fields. If oil were scarce and the potential low there might be some excuse for the argument, but this is not the condition. Again, it may be argued that they desire control of the oil fields to make oil scarce and thus be able to maintain an artificial price. They do desire to make oil scarce to the extent that it shall not demoralize the markets, and to do this they seek the cooperation of the smaller operators.

The opponents of proration say that it is a price-fixing policy. No one denies that when other things are equal scarcity increases price. Proration does not attempt to fix a price. Its only purpose is to maintain a higher price level and to give to each producer his proportionate part of the outlet. The marginal operators should cooperate in this program, because if the price level is lowered they will be the first ones to suffer. The oil industry should not be censored for attempting to restrict supply to save itself from bankruptcy when the Federal Government is attempting to do the very same thing for agriculture and in addition offering to lend to this industry funds to aid it in its purpose.

Benefits from Proration

There are certain legal angles to the problem on which I do not profess competency to discuss. However, it would appear to me as a layman that, in order to promote the economic welfare of the industry and in turn the welfare of those without the industry, the state would be clearly in the right to exercise its police power. Again, the element of

conservation of an exhaustible resource enters into the problem. The production from flush fields, if left unrestrained, would force the abandonment of wells in fields of settled production. This not only results in a loss of oil but in an economic injury to the owners of these properties. So, as a layman, I would say that proration should be sustained by the courts through the right of the state to exercise its police power and, second, to promote the conservation of an exhaustible resource.

One of the chief benefits to be derived from proration is that stocks in storage are being rapidly depleted. The price level of crude oil is still low, owing to the large potential production now existing, but the statistical position of the industry is better now than it was three months ago. If proration is continued and stocks in storage reduced we can expect an upward turn in prices this year. If proration is lifted and production is unrestrained, 60 days' full production will undo what a year's proration program could accomplish. Enough oil could be run into storage in 60 days to fill up the empty storage under a year's proration. If this should happen the industry would be in a worse condition than before proration.

Enforcement of Proration

Proration at best is not satisfactory because the conditions that make it necessary are not satisfactory; also, because potentials are very difficult to compute and because the charges are made that some operators are treated more favorably than others. Also, the claim is made that it is not evenly enforced. When a law is not adequately enforced the need for the law is as important as before. The problem then should be not to repeal the law but to strengthen it. Proration is a cooperative enterprise between the state and the industry. The enforcement of proration in order to make it more equitable should be in the hands of the state. The engineering problems should be undertaken, for example in Oklahoma, by state engineers. They should receive their pay from the state and look to the state for instructions. The umpire should be appointed and paid by the state. The salaries paid these officials should be high enough to attract competent men, men with recognized ability, and men who are competent to see the industry's and public point of view.

Oil Tariff or Embargo

And now we come to the third proposed plan for the stabilization of the industry, the oil tariff. Time and space will not permit extended discussion here of this subject. I was one of the thousand economists who signed the petition requesting President Hoover to veto the present tariff act. It would be reasonable, therefore, to suppose that I would not endorse the proposed tariff on oil or an embargo on petroleum or

petroleum products. Indeed, after studying the problem for some time I cannot see any economic justification for a petroleum tariff. As an economist I cannot see any justification in any kind of protective tariff. In fact, I am firmly convinced that our present tariff law and the one preceding it are among the leading contributing factors to the present depression.

However, I do recommend a temporary embargo on petroleum and petroleum products. An embargo would do no harm and might do some good. An embargo cannot be justified wholly on economic grounds. The domestic production based upon statistics from the U. S. Bureau of Mines is approximately 67 per cent. of the world's production, while the domestic demand is approximately 63 per cent. of the total world demand. These figures are based upon the statistics of the U. S. Bureau of Mines for 1929. There may be some variation for 1930. It is contended by some that there is no domestic overproduction. This contention is so naïve it cannot command serious consideration by thinking persons and can even be disproved by the very statistics used to prove the contrary.

In spite of the fact that an embargo cannot be justified by the logic of economics I would recommend it as a policy of expediency. The small independent producer at the present time has a hard lot. Unless absorbed by the larger companies most of them will sooner or later be forced into bankruptcy. This will be the fault of no one in particular. The prevailing institutions are to blame. The condition is aggravated by the depression. At a time such as this, when oil men's nerves are so near the surface and are sore and strained, it is opportune that steps be taken to improve the morale of the industry. If an embargo will do it and if the small producers want an embargo, let them have it. If a protective tariff is good for some industries and some sections of the country it is good for others. If an embargo on petroleum and petroleum products will relieve the minds of the independent producers it would be the cheapest, the most simple and expedient thing to do and Congress should pass the bill and the President sign it.

Even if an embargo were put upon petroleum and petroleum products, by no means should present proration restraints be relaxed. As long as the United States produces approximately 4 per cent. more petroleum than it consumes, it is producing 4 per cent. too much oil, because, if an embargo is put on, the United States stands to lose most of its foreign markets for domestic production. There would still be a foreign demand for high-grade lubricating oils. An embargo would not seriously affect this class of trade one way or another. Therefore, on this basis production should be further curtailed until domestic production and consumption balance. By this method probably a condition of temporary stabilization could be brought about.

Conclusion

To repeat what was said in the beginning, the institution of property rights and the migratory nature of oil are responsible for the present condition of overproduction. The only way to combat a disease is to eliminate the cause. Palliatives are not permanent cures. The petroleum industry is no exception to the rule. We must look to the institution of property rights and sound engineering practice for relief. The leaders of the oil industry insisted in the beginning on a policy of *laissez faire*. We have lived to see that policy carried to its logical conclusions.

Compulsory unit operation has been suggested at this meeting as a means of securing stabilization of the industry. This plan seems to be very workable. The principal difficulty would be to educate the public and the legislature to put it in force. Knowing public opinion as I do, and being acquainted with the machinery of legislation, I believe it will take some time to achieve any positive results in this direction.

A state compact is another plan that has been suggested—uniform legislation is much to be desired. If the oil states were carrying out a uniform policy today many of the troubles with which the industry is confronted would be eliminated. Although this plan has Secretary Wilbur's endorsement and the sanction of many leaders in the industry and in politics it will never be a success because of conflicting state interest. The idea is good but the difficulty is the securing of uniform enforcement once the compact is made. It stands to reason that the execution of a law of this kind would resemble the enforcement of Prohibition should Prohibition be maintained by state compact.

Some uniformity may be achieved in defining physical waste and in the prevention of physical waste. Physical waste is fairly well under control today. Economic waste is the snag that holds back progress.

It is apparent that if stabilization for the industry is secured there must be coordination of control of production. Recently I suggested to several students of the problem that in order to secure this control a triumvirate be set up consisting of a representative from the independent producers, to be appointed by the Independent Petroleum Association; a representative from the larger integrated companies to be appointed by the American Petroleum Institute, a representative representing the public to be appointed by the President of the United States. All those to whom I suggested this idea turned thumbs down on the proposition.

The petroleum industry is international in its scope. Its problem is too big to depend on state action for its solution. The independent operator has contributed much to the betterment of the industry, but at the same time he has contributed much to its instability. However, the independent operator has won his place and his interests must be protected. It is claimed by the friends of the independent that any

form of control on a national scale will put him out of business. I maintain that for the independent to survive control must be national in its scope. If control is left in the hands of the respective states, thus being decentralized, the independent is doomed. He will not be able to withstand the economic forces that are left in play and his end is near.

I am frank in saying that I see no immediate solution of the problem. Things will work themselves out, it is true. The same thing can be said of famines, plagues and pestilences. Before any kind of plan can be made workable, the industry must get together. There is too much dissension within its own ranks ever to achieve any degree of stabilization. The first thing to do is to unite on a common purpose—have one common aim—and then select a Moses to lead it out of the wilderness.

The time has come for action and the remedy must be drastic. Proration is not the remedy. Tariff and embargo are not the remedy. The industry has been built on a false philosophy of *laissez faire*. Unless the underlying institution of property rights is changed to meet the changed condition, and changed soon, the industry might as well make up its mind to surrender to government control. Unit operation and state compacts are both good plans for solution. The difficulties that confront these plans are not insurmountable. But before they can be achieved, the industry must be united in its opinion.

Production Cost as a Factor in Oil Economics

By H. J. Wasson* and Lucius W. Mayer,† New York, N. Y.

(New York Meeting, February, 1931)

The existing large stocks of raw materials have induced misgivings in the minds of many as to near-view prospects for a return to higher commodity price levels. Until stocks are materially reduced—and this operation will probably extend over a protracted period—a buyers' market will continue. Meanwhile the matter of production cost becomes more and more a factor of consequence to industrial management, finance and the investing public.

With many commodities a general level of costs exists with which the public has been made familiar. Certain conditions surround these industries which, at the outset, determine whether there is a basis for sound commercial results. In other words, it can generally be determined in advance whether or not the cost of production is sufficiently below the normal average price to return a reasonable profit over the years.

With all domestic agricultural products there are available exhaustive Government studies in the field of production costs. Such figures as the average cost of wheat, cotton, sugar, etc., are reiterated constantly. There are many products of foreign origin such as coffee, rubber, raw silk, etc., the production costs of which are to most of us matters of deep mystery. Forest products also are so diversified that few but specialists know what a thousand feet of lumber really cost at the mill, especially where remotely located.

However, with respect to products of mines, production cost information has been widely disseminated. The literature is replete with such data. Here we find that without any special help from outside agencies the industry itself has given publicity to a large variety of cost figures. For example, we know, or know where we can ascertain, the cost of producing a pound of copper from Chile, Arizona or the Lake Superior district. In many cases we can secure from the company reports a vast amount of detail leading up to the cost per ton of ore and the cost per unit of the metal yield. These records are of great assistance to the mining industry as a means of estimating on new exploitations. This industry has been production-cost-minded almost from the beginning.

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Cost of Production of Oil

Though the production of oil may be considered a division of the mining industry, in this activity there is a markedly divergent practice in this matter of cost information. It may not merely be a question of policy; some observers go so far as to aver that the oil industry itself is uninformed as to the cost of oil except in the most general way. Certainly, the investor and the public at large is rarely, if ever, advised officially as to the cost of production; and it also seems evident that insufficient engineering thought has been given to this important phase of the oil business.

Of course, there are individuals who have intimate knowledge concerning costs in specific instances, whether for a lease, a field, or even the entire production operations of one or more particular companies. Even in this respect, however, and among the best informed oil men, one cannot fail to be impressed with the cursory character of *overall* cost data. As to the broader aspect of costs—that is, the weighted average for the industry as a whole, or what might be termed the center of gravity of the crude-oil cost range—we feel certain no adequate studies have been made.

The world's oil requirements can be supplied at some average cost, let us say of x dollars per ton. We should know as much as possible about the magnitude of this variable; not only its magnitude, but its near term trend as well. In the absence of such knowledge, investments in oil properties, and in oil securities, broadly speaking, are handicapped by a highly unsatisfactory element of insecurity.

In ore mining the engineers employed by capital to investigate a given proposition first approach their problem from the standpoint of recovery and realizations costs, of which volume of raw material reserve and of product to be sold are functions; and finally, from the market standpoint. This sequence of reasoning is applicable to all mining undertakings, and obviously it should be the logical procedure applicable to the majority of oil situations. The oil industry, however, has been favored with a combination of rapidly growing consumption, satisfactory prices and the ever-present chance of drilling into enough gusher territory to more than counterbalance the losing projects. Thus, if the innumerable motives that have energized the producing phase of the business may be said to have followed any rational principle, it has clearly been the principle of probability and chance, whereby it was expected that the percentage of paying properties would be sufficient to offset the percentage of losers, the result on balance being a profit. There is no criticism of this lottery principle, so long as the odds are sufficiently in favor of the player. Thus far the oil men by and large have beaten nature on the discovery percentage, and commerce on the price end of the game.

Perhaps the difference in viewpoint between the mining and oil industries can be no better illustrated than in the use of the common word "ore." A combination of minerals which cannot be commercially beneficiated is merely called rock; otherwise it is called ore. That which is ore in one locality may be only rock in another, for the cost of beneficiation may vary sufficiently to totally change the economic result of exploitation under divergent conditions of labor, transportation, power, etc. In contrast to this very generally understood illustration, there is no specific word or phrase to connote a commercial or noncommercial combination of hydrocarbons known as petroleum. Oil seems always to be oil, whether or not this material can be produced profitably. With the oil industry, in general, any tract of land underlain by a rock formation (sandstone or limestone, as a rule) that will exude into a borehole a measurable quantity of liquid hydrocarbons is called an oil property.

To a considerable extent this concept has been in accord with the economics of the situation, or rather with the accepted principles upon which the industry was built, grew up, and thrived; and, in the light of the enormous past financial success of the industry, it might seem of academic interest only whether or not its economics were ever fundamentally sound. However, as a guide to our present and future viewpoint, it is exceedingly important to comprehend the influence that these past results must eventually exert on the industry's destiny. We are conscious of a change, and inquire in our minds whether it is transitory or whether one of the economic fundamentals, dormant for a decade or more, has been at last transgressed to the extent that the forces of retribution have been finally set in motion. Something of this latter nature obviously has occurred, and though nothing much can be done to avoid completion of the adjustment, now that it is in process, we believe it to be of interest to diagnose the problem and attempt to show that its prompt recognition and a change of viewpoint on the part of the composite oil mind may be advocated at this time with benefit and advantage to the industry.

Influence of Oil-scarcity Delusion

The underlying contributory cause largely responsible for the oil industry's present predicament can be traced to the influence of a delusion—the oil-scarcity delusion. Let us say then that it is of a psychological nature. We claim no credit for the diagnosis that the belief in the impermanence of our oil reserves was purely illusory. Perhaps there was even a time when some justification for it existed. We are here concerned with its results which, in a word, we conceive to have been the establishment of oil price on unsound principles wherein the cost of producing the barrel of oil was never a potent consideration. This does not imply that the price of oil has always been either too high or

too low. In its fluctuations through the years oil has perhaps many times sold at a well-adjusted economic price. We, however, emphasize the point that such periods of proper price balance were accidental rather than the results of a freely working economic principle. In practically all other industries it is known that value has a close relation to the cost of production. When costs recede, the price eventually seeks a lower level, as it is impossible to maintain indefinitely more than a certain margin or spread between the two factors in any competitive endeavor. If this margin, that is the profit, be abnormally great, there will be many who, in search of material gain, will seek a participation in the particular industry so favored, and sooner or later through excess production the exceptional margin will be brought down to a base comparable with that of industry in general. It is only in cases of monopoly, such as exist, for example, in the nickel and diamond industries, that resistance to the laws of supply and demand is effective.

Arthur Notman, mining engineer, derives certain figures representing a group of copper companies which have supplied over 60 per cent. of the world's annual output, and points out that for the years 1910 to 1929 inclusive, when copper averaged 16.87 ¢ per pound, "the average margin per pound of copper distributed in bond interest and dividends was 4.27 ¢ or 25.3 per cent. of the average selling price." Similarly, from 1861 to 1910, copper averaged 15.2 ¢ and "the Michigan industry distributed 3.86 ¢ per pound, or 25.4 per cent. of the selling price. During the war years the corresponding figures were 6.30 ¢ per pound, and 27.0 per cent. for copper selling at 23.35 ¢ per pound." These figures confirm that on the average there is little variation in the percentage of average selling price paid out per pound in the copper industry, and emphasize the constancy of the relationship existing between overall cost and the selling price over long periods of time. From Mr. Notman's study it appears that for copper the relation between the selling price and the cost has run along through the years at the ratio of 100 to 75. That is, the industry by and large has been able in the past to sell its product at an average price 33⅓ per cent. above its average cost. A similar relationship probably will hold true in future. Thus, for example, if it appears that the average overall cost of copper is likely to be 10 ¢ per pound for the next decade we can, with considerable confidence, anticipate an average price of 13⅓ ¢ or thereabouts during the period.

Unfortunately, we are handicapped in attempting to apply similar analytical principles to the oil-price problem by the lack of any consistent price-cost relationship.

Intrinsic value—that is, production cost plus a normal profit spread—has not in the past been the unqualified and controlling influence in the price history of crude oil. The preponderant force has been the oil-shortage delusion. The ever-present consciousness on the part of the

industry that an eventual, if not imminent, time would arrive when a barrel of oil would attain values well above those of its historic past, led straight to the correlative delusion that whatever the price of oil, it was cheap. All elements of the industry, large and small, were thoroughly imbued with this belief. Oil purchasers were confident of a future clean-up era, and considered their offering prices largely as discounts of a hypothetical value to be established by scarcity at some later date. It can readily be seen how this price theory furnished incentive to realize profits through inventory appreciation, and satisfactorily explains how large-scale oil storage originated as an investment activity. Following as a natural consequence, competition for the expected profits to be realized from such investment was sufficient to bring about the accumulation of the crude-oil stocks which are now considered so excessive. This same psychology, which carried with it a false sense of profit security and made easy financing possible, also led to land valuations that often gave far too little weight to the normal spread between cost and market of the expected product.

Reduction in Stocks Needed

It is quite unfair to criticize a past policy in the light of a knowledge unappreciated during the years when such policy was evolving. If any criticism is due, it is in the direction of that section of oildom which, with somewhat fanatical unreasonableness, now denounces the oil purchasers as "betrayers of the industry," their alleged crime being the belated liquidation of some of their excess stocks at the expense, of course, of new production which also seeks to be liquidated. The manifest injustice of this accusation hardly requires comment here, as it would seem self-evident that the very first requisite for economic improvement in the oil industry is drastic reduction in stocks. This practically gives a prior right to the owners of stored oil to get their houses in order, and at whatever sacrifice they are inclined to make.

The industry may well reflect over this explanation of how above-ground stocks came to attain their present size; which is intimately connected with the course things will take over the next few years. It is deemed to be certain that the incentive to store oil acquired at prices well above average production cost against an expected future opportunity to sell at a profit has, or shortly will, disappear completely as one of the influences affecting the price level. This incentive may not be expected to reappear until the price of oil actually falls to a level substantially below the known average cost of production. Otherwise expressed, oil has finally assumed the natural tendencies of other commodities, and hereafter demand and supply may be expected to exert undisputed control over price.

Supply a Function of Production Cost

The expression "supply and demand" is so frequently used that sight is often lost of its full implication. It is worth bearing in mind that supply itself is a function of a more fundamental factor, *viz.*, production cost, as has been pointed out by various commentators. The common example is that of a mine which may be said to have a certain amount of ore in reserve at a given production cost and/or selling price. Without any physical change whatsoever this mine will have either more ore or less ore as the cost and/or price fluctuates. Under certain cost and price conditions this mine may be considered to have no ore, and be economically valueless except for the potential value that might ensue with rising price. Similarly, of an oil sand containing 100,000 bbl. to the acre, only 20 per cent. may really be a reserve, because of the prohibitive cost at the existent price level of obtaining the remaining 80 per cent. Reiteration is made by way of these examples because the purpose of this discussion is to draw attention to the importance of production costs now that the belief in an oil scarcity has been dispelled. Again, oil shale is not oil ore, because of the present comparatively high realization cost, yet a sufficient lowering of these costs would make shales a very extensive source of commercially exploitable petroleum. From this end of the scale (which also includes coal and presently unrecoverable oil in depleted fields) we have the enormous range through properties with varying production costs up to the bonanza gusher territory, wherein these costs reach their lowest point. The existence of this great cost range, which necessarily means margin of profit range, is the one heartening feature of the outlook for oil production. No other major commodity has this particular characteristic in any degree comparable to oil. Only the precious metals, rare gem minerals, and certain monopolized commodities, offer similar bonanza situations in which profit becomes completely disassociated from production cost.

Petroleum in general seems rapidly to be approaching an economic equality with coal, about the only difference remaining being that one is a liquid and the other a solid hydrocarbon. Oil production, however, will never be a wholly drab affair. The bonanza oil fields probably will supply increasing percentages of our requirements as time goes on, and by so becoming more and more common will in turn cease to be bonanzas. But even here there will be degrees of rank, and if the 5000-bbl. per day wells become commonplace, the 50,000 and 100,000-bbl. well will still be on an exalted pinnacle of economic desirability.

It is not contended that the glamorous days of oil production are entirely at an end, but it is self-evident that the center of gravity of oil production has been for some time shifting in a perfectly natural way toward the low-cost fields. This trend undoubtedly will continue. A

striking example of such a shift has been in the copper industry, in which it has long been realized that cost is a more important factor governing profit than either price or volume, and for over a long period of years, as previously pointed out, the average distributed profit has remained fairly constant in relation to the average price of the metal.

Fortunately, from a sociological standpoint the principle of oil proration, or artificial curtailment, is tempering the transition with mercy, for an abrupt elimination of all oil outside the low-cost brackets would bring about a calamitous train of results. The point to be emphasized is that in the future it will be insufficient to anticipate the successful development of an oil property merely because a quantity of oil can be obtained from wells drilled on it—for the cost factor must first be satisfactorily answered. That is, a careful computation of overall costs must show a reasonable profit spread in the light of a future oil-price base determined rationally by the average production cost of all other oil, this being the factor which in combination with "normal profit spread" establishes the intrinsic value over a period of time, and hence market value, of all nonmonopolized raw materials.

Conclusion

The authors have presented the foregoing notes in the hope that engineering thought may thereby be stimulated in the direction of the study of oil costs beyond merely the limited horizon of drilling, pumping, etc. Moreover, cost data should occupy its proper place in the annual reports of oil companies. Stockholders thus far have provided the required money pretty largely on faith. They may possibly continue to do so, but the financial management of an oil company will more wholesomely fulfill the obligations of its trusteeship when it undertakes to inform its shareholders regarding the cost of obtaining the product upon which the industry is based.

Economics of the Crude Oil Potential in the United States

By Joseph E. Pogue,* New York, N. Y.

(New York Meeting, February, 1931)

It is the purpose of this paper to attempt to establish three theses which may be stated in advance as follows:

1. The crude oil potential is the accumulation of surplus initial production.

2. The crude oil potential is a semi-inventory and therefore is a causal factor in the price of crude petroleum.

3. The price of crude petroleum no longer correlates with above-ground inventories but does correlate with corrected inventories (*i. e.*, above-ground storage plus the inventory equivalent of the crude oil potential).

The factors and principles set forth in this study are thought to yield an approximate answer to a number of questions of active interest in the petroleum industry today, to wit:

(*a*) How long would be required to eliminate the potential if all drilling ceased?

(*b*) What would be the indicated crude oil production of the United States in 1931 if proration were abandoned?

(*c*) What economic change would be necessary to warrant a higher price for crude oil?

Definitions

For the purposes of this study the following definitions may be stated:

The *crude oil potential in the United States* is the quantity of oil that all the oil wells would make the first 24 hr. if permitted to flow unrestricted.

The *surplus potential* is the above-mentioned quantity minus the volume currently produced.

Initial production is the first day's unrestricted flow of an oil well.

Aggregate initial production is the sum of the initials of all wells completed during a year.

Surplus initial is the initial not needed to bring production into balance with demand. The surplus initial is equal to the crude oil potential minus the current rate of production.

The *annual production-equivalent* of the crude oil potential is the volume of oil that would be produced in one year if all wells were permitted

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to flow normally with no new wells completed. The *inventory-equivalent* of the crude oil potential is the volume of above-ground storage that would have the same economic effect as the potential.

Relation of Initial to Potential

Table 1 shows the method of determining the factor relating the aggregate initial of wells completed in a year to the annual production of these wells. The period covered is the 12 years, 1916–1927, antedating the general practice of proration. With an annual decline of old production approximating 25 per cent., the ratio of aggregate initial to its annual production equivalent centers around 52, which is the median of the 12 ratios. Thus if we multiply the aggregate initial for any given year by 52, we obtain the annual production contributed by the initial of all new wells during the year.

Table 1 reveals that the aggregate initial in 1928, 1929 and 1930 ran substantially higher than in previous years and above the trend for the

Table 1.—*Determination of Relation between Initial Production and Annual Rate of Production of Crude Oil in United States*

Year	1 Actual Production, Million Bbl.	2 Estimated Production without Drilling during Year (75% of Previous Year's Production), Million Bbl.	3 Difference to be Contributed by Aggregate Initial Production for Year, Million Bbl.	4 Aggregate Initial Production of New Wells,[a] Million Bbl.	5 Ratio of "Difference" to Aggregate Initial, Col. 3 ÷ Col. 4[b]
1916	301	211	90	1.601	56
1917	335	225	100	1.511	67
1918	356	251	105	1.614	65
1919	378	267	111	3.554	31
1920	443	283	160	3.508	46
1921	472	332	140	2.828	50
1922	558	354	204	4.266	48
1923	732	419	313	6.105	51
1924	714	549	165	3.255	51
1925	764	535	229	4.300	53
1926	771	572	199	3.684	54
1927	901	579	322	4.918	65
1928	901	675	226	8.366	
1929	1007	675	332	6.170	
1930	896	756	140	9.956	

[a] From *Oil & Gas Jnl.* (Jan. 29, 1931) 94.

[b] The median ratio is 52; thus the aggregate initial for any given year may be converted into its annual production equivalent by multiplying the aggregate initial by 52.

series. Table 2 shows the portion of the aggregate initial that was not needed to take up the decline of old wells and which was consequently left over as surplus initial. Under proration, this surplus initial was held underground in the form of potential production. Table 2 shows that in the past three years the summation of the surplus initial is approximately 11.1 million barrels. Theoretically this figure should coincide with the surplus potential; that is, the actual potential minus current production. The actual potential of the country is not precisely known, but the indications are that at the close of 1930 it was running in the neighborhood of 13.5 to 14.0 million barrels. A calculation of the rated potential of the United States as of Nov. 1, 1930, made by the statistical department of a large oil company and published in Rinehart's Oil Report of Dec. 1, 1930, places the potential at 13.8 million barrels. If we subtract from this figure the November daily production of 2,289,000 bbl., the resulting surplus, or shut-in, potential becomes 11.5 million barrels. This figure compares closely with the 11.1 million barrels calculated in Table 2 as the surplus initial that has accumulated during the past three years. The close agreement of the two figures, in view of the generalized character of the data, is regarded as establishing the thesis that the shut-in potential is the summation of the surplus initial, a conclusion also valid on logical grounds alone. Therefore surplus initial and surplus potential are one and the same thing.

TABLE 2.—*Determination of Surplus Initial (Potential) Brought in in United States*

Year	1 Aggregate Initial, Million Bbl.	2 Initial Needed to Balance Decline of Old Production (Col. 3 of Table 1 + 52), Million Bbl.	3 Surplus Initial Left Over in Form of Crude Oil Potential, Million Bbl.
1928	8.366	4.350	4.016
1929	6.170	6.380	− 0.210
1930	9.956	2.695	7.261
Total	24.492	13.425	11.067

It is apparent that the development of this large shut-in potential is the result of the policy of curtailment through proration of production as followed by the petroleum industry in the United States during the past three years.

Production Equivalent of Shut-in Potential

To determine the economic effect of the shut-in potential, it is necessary to know the production-equivalent of the potential. This calculation follows from the data in Tables 1 and 2 and is presented in Table

3, which shows that in 1928 a production of 208 million barrels was suppressed; in 1929, the potential declined slightly; and in 1930, a production of 377 million barrels was held back in the ground. For the three-year period, 1928–1930, a crude oil production of 574 million barrels was suppressed by curtailment of completed wells and this figure, consequently, is the volume of crude oil that our shut-in potential would yield in one year if the wells involved were permitted to flow normally.

TABLE 3.—*Annual Production in* 1928, 1929 *and* 1930 *Suppressed in the Form of Crude Oil Potential*

Year	1 Surplus Initial (Col. 3, Table 2), Million Bbl.	2 Equivalent in Annual Production (Col. 1 × 52), Million Bbl.	3 Actual Production, Million Bbl.	4 Corrected Production if Potential Had Been Produced (Col. 2 and Col. 3), Million Bbl.
1928	4.016	208	901	1109
1929	−0.210	− 11	1007	996
1930	7.261	377	896	1273

To determine the 1931 production if restrictions were removed, we may make the following calculation:

	MILLION BBL.
Production from old wells	672
Production from shut-in potential	574
Estimated production from drilling under way	260
Total	1,506

Thus if proration were abandoned, the theoretical production of the United States in 1931 would be 1.5 billion barrels, or about 70 per cent. in excess of expected demand.

INVENTORY-EQUIVALENT OF THE SHUT-IN POTENTIAL

Having established a method of converting shut-in potential into its annual production-equivalent, it now becomes possible to measure the economic effect of the potential. Obviously, if the shut-in production were *actually* produced, its effect would become that of actual production, the excess going into storage and adding to the weight of the above-ground inventory. So long as the potential is held in the ground, however, the effect is less than if the oil were actually produced, for the reason that the lifting and storage costs are saved. Yet the effect is substantial because the drilling cost has been expended. The effect of the shut-in potential is obviously less than that of its annual production-equivalent by some indeterminate percentage. As drilling costs are by and large roughly one-half the sum of lifting and storage costs, it is logical to assume that if we take one-half the annual production-equiva-

lent of the shut-in potential and add this quantity to inventory, we obtain a tentatively satisfactory measure of the economic weight of the potential.[1]

In Table 4 the inventory-equivalent of the shut-in potential (*i. e.* surplus initial) is calculated for the past three years, and it is seen that the shut-in potential of the United States has the economic effect of an addition of 287 million barrels to above-ground inventories. It follows that this condition is bound to have an unfavorable effect upon the market structure.

TABLE 4.—*Calculation of Inventory-equivalent of Crude Oil Potential in* 1928, 1929 *and* 1930

Year	Annual Production-equivalent of Surplus Initial (*i. e.*, Surplus Crude Oil Potential) (Col. 2, Table 3), Million Bbl.	Inventory-equivalent of Surplus Initial (Col. 1 ÷ 2),[a] Million Bbl.
1928	208	+104.0
1929	− 11	− 5.5
1930	377	+188.5

[a] Assumption: Drilled-up oil stored underground has one-half the economic effect of above-ground inventories.

Correlation of Inventory with Price

Commodities in general show a high degree of inverse correlation between price and inventories, especially if inventories are related to consumption through the device of expressing inventories in number of days' supply. Table 5 and Fig. 1 show this correlation for petroleum, the two series chosen for comparison being stocks of all oil and the average price of Mid-Continent crude oil (33.0–38.9 gravity). In Table 5 the data and calculations are presented, while in Fig. 1 the correlation is shown graphically. For convenience of visualization, the inventory is plotted on an inverted scale in Fig. 1 in order that the two series may be directly compared. (Technically, this device changes an inverse correlation into a direct correlation.) The correlation is presented in two stages: (1) The relation between price and above-ground inventories; and (2) the relation between price and above-ground inventories corrected (in 1928, 1929, and 1930) for the inventory-equivalent of the shut-in potential.

Fig. 1 reveals that for the period 1918–1927 a high degree of correlation exists between price and above-ground inventories. This relationship, however, does not hold for the past three years, 1928–1930, price declining far below the levels indicated by the above-ground inventory

[1] Later on it may be possible to establish a more exact discount factor to be applied to the annual production-equivalent.

TABLE 5.—*Correlation of Price of Crude Oil with Inventory of All Oil Expressed in Days' Supply and Corrected in* 1928, 1929 *and* 1930 *for Inventory-equivalent of Crude Oil Potential*

Year	1 Consumption of All Oil, Million Bbl.	2 Inventory of All Oil in U. S., Million Bbl.	3 Inventory Expressed in Number of Days' Supply	4 Inventory-equivalent of Crude Oil Potential, Million Bbl.	5 Corrected Inventory (Col. 2 and 4) Million Bbl.	6 Corrected Inventory Expressed in Number of Days' Supply	7 Average Price Mid-Continent Crude Oil, Per Bbl.
1918	427	193	165		193	165	$2.19
1919	438	197	164		197	164	2.29
1920	535	227	155		227	155	3.41
1921	528	294	203		294	203	1.65
1922	605	396	239		396	239	1.68
1923	754	485	234		485	234	1.56
1924	805	520	236		520	236	1.57
1925	841	550	238		550	238	1.79
1926	913	526	210		526	210	2.09
1927	944	597	232		597	232	1.37
1928	1015	620	223	104.0	724	260	1.30
1929	1103	689	228	98.5	788	260	1.35
1930	1080	666	227	287.0	953	322	1.22[a]

[a] Price Dec. 31, 1930, $0.93 per barrel.

series. If, however, we correct the above-ground inventories for 1928–1930 by adding the inventory-equivalent of the shut-in potential, the correlation resumes and the normal price-inventory relationship obtains. This correlation study is believed to demonstrate that the shut-in potential is a semi-inventory and as such exerts a normal adverse effect upon the price structure. In no other way can the crude oil price level in 1928–1930 be satisfactorily explained. Were the potential without economic effect, the price of average Mid-Continent crude would today be between $1.50 and $1.75 per barrel, instead of $0.93 per barrel.

FURTHER ECONOMIC CONSIDERATIONS

From the data presented here it may be calculated that if all drilling ceased our potential would be sufficient to maintain the supply of crude petroleum in overall balance with demand for approximately 28 months. At the end of this period, a price of $1.75 for Mid-Continent crude oil would be indicated. Under subnormal drilling (with an annual initial of 2.5 million barrels), 50 months would be required to eliminate the crude oil potential. As complete cessation of drilling is not practicable,

it follows that the petroleum industry must be prepared to endure low crude oil prices until the potential can be substantially reduced. Unfortunately, the potential is still increasing and it seems imperative that efforts be directed towards reversing this unfavorable trend, else still lower prices may be called forth to halt this movement.

This study indicates clearly that if the purpose of curtailment of production in the petroleum industry was to maintain a satisfactory price, the technique developed was faulty because it did not really control

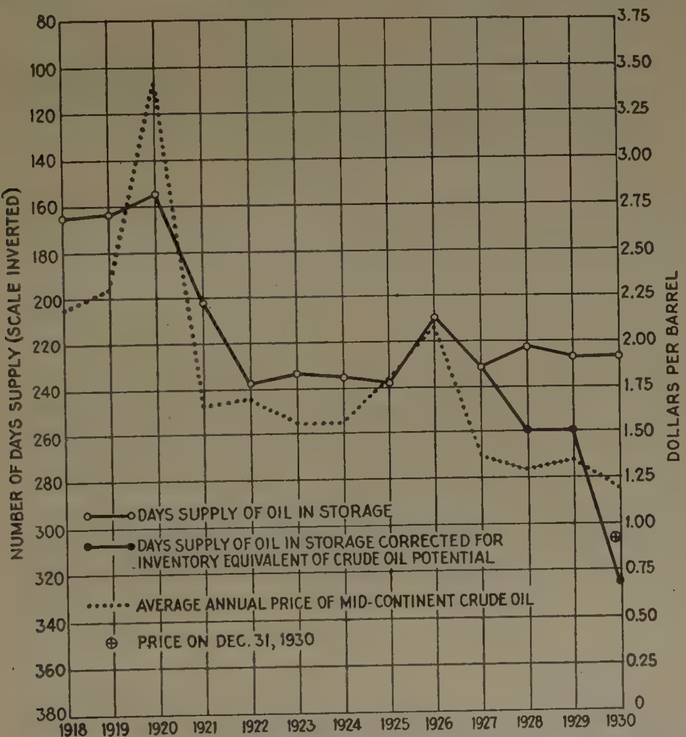

Fig. 1.—Correlation of oil inventories and crude oil price by years, 1918–1930.

production in an economic sense, but permitted the inventory position of oil to become progressively more adverse. Contrariwise, it follows that if artificial stabilization in the petroleum is to succeed, control must be exercised over the potential to the end that this factor may (1) be stopped from increasing and (2) be gradually reduced.

The adverse economic effect of the potential may be minimized either by reducing the potential or by increasing the proportion of the potential that is under unit, rather than competitive, influences. The potential itself is not homogeneous but divides into two portions—the unitized and the competitive—which have unequal economic weights. This

aspect of the problem is involved and can be only lightly touched on in this place.

It follows that if the principles outlined in this paper are correct, the industry can obtain a remunerative price level for crude oil only by reducing the corrected inventory. The reduction of above-ground inventories will not alone suffice, as adequately proved by the events of 1930; the combined inventory (above-ground and potential) must be lowered. The combined inventory at the close of 1930 represented 322 days' supply, with price at $0.93 per barrel. If a price level of $1.50 is desired, combined inventories must be reduced to 225 days' supply, or approximately one-third. Any methods for stabilizing the crude oil situation that do not involve a reduction in combined inventories would appear to fall short of a fundamental approach to the problem.

Conclusions

1. The shut-in crude oil potential is the summation of the surplus initial production brought in during the past three years.
2. The potential has the economic effect of an inventory, the effect being approximately one-half that of the potential converted into actual production.
3. The price of crude oil correlates with above-ground inventories corrected by adding thereto the inventory equivalent of the potential.
4. If all drilling ceased, the potential would be sufficient to maintain crude oil production in balance with demand for 28 months.
5. If all restrictions were removed and the oil could be handled physically, the crude petroleum output of the United States in 1931 would be 1.5 billion barrels. In such event, the price of Mid-Continent crude oil would have an indicated decline to 10¢ per barrel.
6. The crude oil potential is still increasing, thus exerting pressure on crude oil markets.
7. If a higher crude oil price level is desired by the petroleum industry, some method of reducing the crude oil potential must be found.
8. The methods of control thus far practiced in the petroleum industry are faulty to the extent that they may have permitted the potential to increase.
9. Any methods for stabilizing the petroleum industry that do not involve a reduction in the economic effect of the combined inventory are not fundamental and cannot be counted on to succeed.

DISCUSSION

(*C. V. Millikan presiding*)

J. E. Pogue.—In my judgment, the imports of oil have not been a primary cause in the downward trend of oil prices, because oil imports have approximately been constant throughout this period. The ratio of imports to domestic production has

not increased. If our imports of oil were suddenly eliminated by embargo or prohibitive tariffs, oil prices would doubtless rise, and this would have the effect of stimulating domestic production to higher levels. At the same time the oil formerly imported would be forced into foreign markets, replacing equivalent quantities of our oil exports. The result would be an increase in the world's production of oil, without a corresponding increase in the world's consumption of oil. Thus the statistical balance for the world would be worsened and improvement in this country would be temporary. There are some who advocate that this country should become self-sufficient in oil, arbitrarily keeping out oil imports and suffering a loss of our foreign markets. If the world should adopt such a policy, it would prove a backward step as defeating the international movement of commodities upon which progress in world trade depends.

D. R. Snow,* Tulsa, Okla.—The East Texas situation offers many problems. It extends from the Joiner area, which was brought in two or three months ago, where the wells are rather small, to the Bateman Crim well, which is approximately 10 miles north, and then on north of the Lathrop well, approximately 12 to 13 miles farther on, making a total extension of nearly 25 miles. Each one of the two wells last mentioned had an estimated initial of approximately 19,000 bbl. Those initials weer estimated on very small time flow, about 40 or 50 min.; I do not believe that anyone familiar with those wells expects them to produce anything like that amount over a period of time as long as 24 hr. or more.

Two points about the field are particularly interesting from the standpoint of its possibilities—the thickness of the sand and the pressure on the wells. The sand pinches out to the east and thickens to the west. There is no dome structure as in other East Texas fields, such as Van and Powell. In the Joiner area a very thin sand was found. The Deep Rock well drilled something like 20 ft. of sand, and the deepest sand that has been drilled in any of the wells is 25 to 30 ft., not over 30 ft., and apparently it has been drilled through. It is possible that some wells farther west will have a little greater thickness of sand. Another point of interest is the low rock pressure of the wells. It amounts to a shut-in pressure of approximately 450 lb. For a depth of around 3600 ft., that is really subnormal. The gas ratio is also low. That leads to the conclusion that probably the wells will have a short life in flowing and will require artificial production, thus making it more expensive to produce them.

I suppose everyone knows that approximately 12,000 bbl. per day of 40° gravity oil is being shipped out of the field now, mainly in tank cars. The field is well located with reference to transportation facilities, having two main railroad lines, an east and west line, the Texas & Pacific and a north and south line to the Gulf. Ten or twelve thousand barrels of production are going out, which are being sold at a price varying from 35¢ to 45¢, probably averaging around 40 cents.

Member.—What about the probability of rapid drilling due to small acreage?

D. R. Snow.—The land lines are the old Spanish survey lines cut up into extremely small tracts, from 10 to 200 acres. Two hundred acres is a large tract. Probably the tracts do not average much over 80 acres, and undoubtedly there will arise some of the troubles that occurred in the Van field, of excess strips caused by irregularity and poor description in the old surveys. It is probable, therefore, that drilling will be closely spaced and difficult to control. Another interesting thing is that the field is being developed largely by independent operators, men who come in with a few thousand dollars. They can complete a well for $22,500 into the tanks, and these operators, whether or not they have been harmed by proration in other areas, think

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that they have, and have taken a stubborn stand against it. However, I do not see how the field can fail to have some sort of proration.

C. E. BEECHER,* Bartlesville, Okla.—Are the pressures in the two northern pools the same as in the Joiner pool, or are they higher at that end?

D. R. SNOW.—There is no difference to speak of. The cessation in flow of the wells in the Joiner area was caused by the amount of sand encountered, I believe. I think they simply had a very small amount of reserve production because of the thickness of sand, and it is not at all a question of the difference of pressure.

F. H. LAHEE,† Dallas, Tex.—There are two rather interesting facts in connection with this field. At Van and also at Kettleman Hills, which are the two outstanding instances of proration, or unitization, there was originally a rather definitely known geological structure to guide in outlining the acreage to be included. In the present case there is absolutely no knowledge of what the structure is going to be or whether, in fact, there is a structure; how big the field is going to be, how wide it is going to be; whether there is one field or several fields. In other words, we have absolutely no way of getting at the boundary as a starting point.

The other fact that I think may be interesting to some is geological. The producing sand here was not deposited out toward the west from the old land mass of the Sabine Uplift. Apparently it was carried into the old Cretaceous sea from the northwest and north. It happened to overlap the west edge of the Sabine Uplift. That is to say, its source was not to the east; it is simply the feather edge of sand which came from an entirely different direction.

C. V. MILLIKAN,‡ Tulsa, Okla.—What is the consensus of opinion of the geologists who are more familiar with that district as to the extent of the sand? Is it the general opinion that that is one continuous pool, or do most of them hold to the opinion that it is a series of smaller pools?

F. H. LAHEE.—As far as we know now, and I believe this was known some time ago, before any drilling occurred, there is a slight indication of an anticlinal nosing towards the west in the position of each one of the discovery wells. These are very broad bowings, but they suggest the possibility of local pools. However, the three wells are producing from the Woodbine sand within rather narrow limits of depth below sea level. They are all producing in approximately the same position towards the eastward edging out of the Woodbine sand and, therefore, there is a fairly good reason to believe that oil may be distributed completely through the entire zone and perhaps farther south and farther north than the most southern and most northern oil producers at this time. Actually these are the only facts which we have to work on.

F. J. FOHS,§ New York, N. Y.—The extension to the south will be limited by the Jacksonville fault zone, on the south of which Woodbine was encountered but showed no oil. It is possible that a feather edge of the pool will extend south to this zone. Further south the sand proved present with some saturation in the Magnolia test, and continues to have possibilities if found high enough, north of its south limit, which occurs some distance south. Eastward, south of the fault zone, it has nowhere been penetrated. Northeast, around the Sabine Uplift, toward the Wascomb gas area, the contours on the Woodbine Sand, or Tokio, appear to rise rapidly, and unless the sand

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§ Consulting Oil Geologist.

body shows locally a marked interruption in dip, I do not expect oil pools to be found. Neither do I expect the field to extend much north of the present most northerly well. The extent of the rise to the northeast may account for the absence of a greater amount of gas in the pool.

C. V. MILLIKAN.—Do you think there is a possibility that this field might extend to the Wascomb gas area?

F. J. FOHS.—I do not.

F. H. LAHEE.—Mr. Fohs' remarks lead me to point out an error which has been made by a great many, and unfortunately has recently been published: a tendency to contour the Woodbine sand up into the Nacatoch sand, carrying the contours up into the higher sands. Geologists will have to be very careful lest the engineers get a wrong impression from these maps. The Woodbine sand has an east edge which runs between a north-south trend and a trend north 20° east through a point just east of the southeast corner of Smith County. It does not turn eastward in a distinct arc. It does not run up on to the Sabine Uplift, as this recent map shows. I am not sure which fault Mr. Fohs means, but there is a fault to the southwest, in Cherokee County, which was drilled, and as far as I know this is the only case of a well that flowed up into the derrick and never seemed to create any excitement.

F. J. FOHS.—The oil flow of which Mr. Lahee speaks was on the fault zone I referred to, but to the best of our knowledge, the oil in the Colliton well came from the Blossom sand—not from the Woodbine.

Chapter VI. Refining

Developments in Refinery Engineering during 1930

By H. W. Camp,* Tulsa, Okla.

(New York Meeting, February, 1931)

In attempting to summarize and pick out the outstanding developments in refinery engineering during the past 12 or 13 months, one is immediately impressed by the great strides that have taken place. It is, of course, difficult to obtain the proper perspective with the old year so fresh in our minds, and if relatively minor improvements seem to be given equal recognition with those of magnitude, it will be because the nature of the human mind causes us to place the trivial incidents of today with the important things of yesterday. For instance, the Twenty-Second Semiannual Motor Gasoline Survey (December, 1930) of the U. S. Bureau of Mines shows that the total gasoline yield per barrel of crude increased from 39.6 per cent. in 1929 to 41.99 per cent. in 1930. This latter fact may appear rather confusing since the production of high-gravity crudes has been steadily increasing. However, during the past year there has been a reduction in gasoline end point of approximately 8° F. which roughly corresponds to about 1.0 per cent. yield from the crude oil. It appears, therefore, that if the gasoline were based on a corresponding distillation basis 1930 would show better yields from the crude than 1929. Cracked gasoline increased from 14.83 per cent. in 1929 to 17.46 per cent. in 1930. Percentage of total gasoline from cracking stills has doubled since 1925, thus indicating the extent to which this phase of refining has advanced over past years.

Replacement of the old shell still batteries by a pipe still and single flash system, with an efficient fractionating tower, has proved advantageous both in fuel consumption and in decreasing space required for the installation.

Considerable activity has been shown in the field of vapor-phase cracking, with the development of several new types of units. The production of a product with a high antiknock value makes the vapor-phase processes particularly attractive. Cracking equipment has shown a marked advance with the development of corrosion-resisting alloys. Nickel, chromium and vanadium have shown interesting possibilities, but as yet are fairly expensive. Ceramic material for lining reaction

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chambers has been widely accepted for reducing corrosion. There is a great deal of controversy as to whether chemical treatment of charging stock is more or less economical than the use of corrosion-resisting alloys. Certainly the greatest future lies in the development of the metallic alloys, since no hope of improvement is apparent by chemical treatment alone.

The use of gas engines for motivating pressure-still hot-oil pumps has long been a possibility, but until recently mechanical difficulties have prevented their general use. Recent developments have now opened up this new use for gas engines, and the new installations have completely justified their use. The fuel saving is rather obvious, and investment costs are said to be lower when considering additional boiler-house capacity for generation of steam when steam pumps are used.

The installation of pressure distillate stabilizers has gained impetus during 1930. Distillate from the pressure distillate receiver is passed through a stabilizing column where all the propane is removed and enough of the butane fraction to insure a low vapor pressure product. This system reduces handling losses, chemical treating costs and controls the volatility of the final product. One of the latest innovations is that of rerunning pressure distillate under vacuum. The previous methods involved shell stills or conventional pipe stills. By using the gas-oil bottoms as a heating medium and thereby never allowing the pressure distillate to be overheated, and by distilling under partial vacuum, the gasoline does not undergo the harmful effects common while distilling pressure products by ordinary methods. In addition to the improved quality of the overhead product, there is a considerable saving in fuel and treating costs, since the oil is not heated to so high a temperature and no steam is used.

Hydrogenation

Hydrogenation probably has elicited the greatest comment and interest of all subjects brought to the attention of the oil industry and general public alike. There is something romantic about the statement that a barrel of oil will yield a barrel of gasoline. The hydrogenation of petroleum has been an adaptation of the process for hydrogenation of coal, developed in Germany by the I. G. Fahrenindustrie. The development work in this country has been carried on by the Standard Oil Co. of New Jersey, and more recently a patent club has been organized in which all the major oil companies now hold an interest in this process.

The process consists in passing a mixture of petroleum and hydrogen into a reaction chamber at 3000 to 4000 lb. per square inch, and in the presence of a corrosion-resisting catalyst the hydrogenation takes place. The products leaving the reaction zone are processed as are other petroleum fractions. It is significant that hydrogenated oils are practically

free of unstable compounds and asphaltic matter. Sulfur is eliminated, and the quality of the products is claimed to be superior to that of the original oil.

Recent tests on gasoline made from this process show exceptional antiknock characteristics, and, unlike cracked gasoline, the antiknock value increases slightly with increased boiling point. Gasoline having an octane number of 95 has been made. Exceptional stability to gum formation by the oxygen bomb method has also been reported.

Lubricants made by this process are said to be of exceptional quality. These lubricants have been subjected to actual engine tests and satisfactory results have been reported.

It is not at all unlikely that a plant could be designed with balanced skimming, cracking and hydrogenation facilities to manufacture whatever products are most desirable, and in whatever percentages they are desired.

Refrigeration and Dewaxing

The tendency toward low cold-test motor oils has been more pronounced during the past year than any previous one. This tendency has been reflected in increased refrigeration and dewaxing equipment. Centrifuging remains the predominant method for wax removal, although several large installations of the filter aid processes have been made. Very little progress in solvent dewaxing has been noted. There is at least one installation where centrifuging is combined with the filter aid process. This unique combination is said to increase centrifuge capacity by using the filter aid for cloud removal.

An interesting feature in refrigeration recently developed involves the use of dewaxed oil for the cooling medium instead of salt brine. The advantages of this method are quickly apparent. The elimination of brine reduces the process by one system, reduces corrosion and increases ease of operation. The oil for dewaxing is passed in series through a battery of chillers where it is contacted with the dewaxed oil. The last of the chillers are direct ammonia expansion type which reduces the oil to approximately $-40°$ F., from whence it passes directly to the centrifuges. Dewaxed oil from the centrifuges is further chilled by direct ammonia expansion, from whence it passes through the chillers, going to storage. Very efficient exchange of refrigeration is accomplished at minimum expense.

New Equipment

Numerous vacuum units, for manufacture of overhead lubricating oils, have been installed, and several companies have products manufactured by this method on the market at the present time. Distillation at reduced pressure has long been recognized as the ideal way of manu-

facturing lubricating oils. Excessive heat and steam required for atmospheric distillation have resulted in high fuel costs and injury of products caused by high temperatures necessary for the distillation at atmospheric pressure. Products from the vacuum unit are extremely light in color—uncontaminated by asphaltic material. The chief advantages of vacuum distillation are use of dark crudes, heretofore unusable for manufacture of lubrication oil, lighter colored oils, low-carbon residue, closer fractionated product, lower volatility, lower sulfur content and generally lower treating costs and losses.

The refiner has been first to recognize evaporation loss, because he has to deal with the more volatile constituents in their finished form. This has been accomplished by gas-collecting systems from the tanks of compression or absorption recovery plants. Wooden or metal roofs are becoming things of the past, because of the development of modern vapor-tight steel roof, together with floating and breather type tank roofs. One of the outstanding developments for conserving vapor losses this year is the Wiggin's steel balloon, which not only lends itself to petroleum refining but to the production and natural gasoline industry.

The past year has seen the installation of semiautomatic equipment such as continuous treaters, automatic blending devices, mixers, liquid-level controllers, and temperature controls. A definite step toward the automatically controlled refinery is unmistakable. Under the pressure of low prices for refined products the refiner is ready to grasp any small device or piece of equipment that will save a few dollars and reduce operation costs.

It is not too much to expect the refinery of the future to be a completely balanced unit. Producing gasoline, fuel oil and coke, it has an abundance of fuel available for operation of gas engines, steam plants and complete electrical power units. A recently built refinery near Denver, Colo., is almost entirely operated by electrical power.

Lead-base greases are receiving a great deal of thought by grease manufacturers and motor car manufacturers alike. High-pressure grease kettles for quick saponification have been installed in many plants, indicating the general trend toward more efficient operations, with increased quality products.

Many refiners have turned their acid sludge into a revenue by installing mixing and burning equipment. A few years ago the sludge pond was the eyesore for every refinery, but these ponds are now just reminders of the days when every drop of oil was not necessary for a good earnings statement.

Transportation of Gasoline

One of the major developments during 1930 was in the field of transportation, the rail rates in many instances being so high as to prevent

competition with gasoline made at the point of destination from crude oil transported by pipe line. This inequality has been felt most severely during the past year under the stress caused by low gasoline prices. Two principal solutions have resulted—the transportation of gasoline by pipe line or by tank truck.

Electric welding, seamless steel tubing, and many improvements in pipe line construction have made it possible and highly advantageous to transport petroleum products by this method. Lines with operating pressures over 1000 lb. per square inch are now under construction. It is not surprising that gasoline should be transported by this method, and at a much lower cost than by rail. The entire oil industry from coast to coast has adopted this form of transportation.

Transportation by large tank trucks is particularly economical in certain localities. Large motor trucks with from one to three trailer tanks make up the cargo. Aluminum tanks and aluminum alloy chassis reduce the dead weight to a large degree, increasing the pay load by a corresponding amount. This method of transportation is proving particularly economical in densely populated areas having paved highways, where trips are relatively short and a considerable gallonage must be handled.

Refining Up to Date

The refiner is alert to all possibilities for improvement, and in conjunction with the various research agencies which he is supporting should register still greater advances during the ensuing year. The refiner in 1930 has kept pace with other branches of the industry. He has not struck any gushers to cause comment, but his progress has been one that must be recognized in the oil industry as affecting the overall picture.

Chemistry and engineering are allied in refining more closely than ever before, and through this alliance it is expected that many new products will be developed which will materially assist in increased profits under prevailing low prices. Overproduction of crude oil and large stocks of gasoline do not promise much hope of better prices soon, hence the development of by-products should receive the attention of everyone in the industry.

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(NOTE: In this index the names of authors of papers and discussions and of men referred to are printed in SMALL CAPITALS, and the titles of papers in *italics*.)

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